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TRAIN LOCATION IDENTIFICATION AND CONTROL SYSTEM
LICS PROTOTYPE EQUIPMENT CONSTRUCTION

Prepared By
Glenayre Electronics Ltd.

For The
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Train Location Identification and Control System
LICS Prototype Equipment Construction

Final Report

by

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17. Abstract

A development project carried out during the period December 1978 to March 1981, is reported. The objective of the project was to improve the detailed design of the LIC train borne equipment through the application of recent advances in microprocessor technology. The Engine Logic Unit (ELU), Cab Display Unit (CDU) and transponder detection logic designs were reviewed, re-designed, tested and de-bugged. The new design was based on the fixed block method of control as opposed to its moving block predecessor; the system no longer displays speed-limits. Three complete sets of prototype equipment were produced and factory tested according to a series of controlled functional and environmental tests. Following successful completion of these tests, the units were installed on three British Columbia Rail locomotives and three cabooses. The equipment was field tested over a one month basic tracking period. Each of the test phases with the exception of transponder reporting was a success. A rework phase corrected transponder reporting and a success rate of above 99% was finally achieved.

The resulting equipment designs were found to be more flexible, reliable and suitable for railway applications. It is recommended that a full set of production units be built, for use in an operational LIC system to be installed on the Squamish Subdivision of B.C. Railway.

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17. Résumé

Ce rapport décrit les travaux de développement exécutés de décembre 1978 à mars 1981 et relatifs aux expérimentations faites sur les matériels embarqués du système LIC (système pour la localisation, l'identification et la commande automatiques des trains) amélioré par l'application de systèmes informatiques avancés. Le circuit logique de commande de la locomotive, le tableau d'affichage en cabine et le circuit logique du transpondeur ont été réexaminés, réétudiés, essayés et mis au point. Le nouveau modèle est fondé sur une régulation par cantons fixes et non plus par cantons mobiles, comme c'était le cas auparavant, et le système n'affiche plus les limites de vitesses à respecter. Trois jeux complets de matériels à l'état de prototype ont été construits et éprouvés en usine dans des conditions de marche et d'environnement contrôlées. Une fois ces essais achevés avec succès, les matériels visés ont été installés à bord de trois locomotives de la B.C. Rail et de trois wagons de queue. Les essais in situ qui ont suivi et portant sur la capacité de repérage de ces matériels ont duré un mois. Les essais de chacun des éléments ont été couronnés de succès, sauf ceux du transpondeur dont le taux de réponse était insuffisant. Mais un taux supérieur à 99 pour cent a pu être finalement obtenu après une mise au point du transpondeur.

Le modèle ainsi mis au point a été trouvé plus souple d'emploi, plus fiable et mieux adaptable aux applications ferroviaires. Le rapport termine en recommandant de passer à l'étape de la fabrication en série d'un jeu complet de matériels LIC, à être mis en service dans la subdivision de Squamish appartenant à B.C. Rail.

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EXECUTIVE SUMMARY

1. OBJECTIVES

Glenayre Electronics was awarded a contract for further development of the LIC train borne equipment, to meet the requirements of the BC Railway implementation. This contract was known as the LIC pre-production prototype development project.

The objectives of this project were to:

a) Review the designs of the LIC electronic equipment in the light of the performance analysis which had been carried out, and the field experience gained with the trial LIC system on BC Railway.

b) Produce an updated design for the locomotive mounted engine logic unit (ELU) and the cab display unit (CDU).

c) construct and test three complete sets of ELU and CDU pre-production prototype equipment.

2. DEVELOPMENT WORK

The primary work done during the pre-production prototype project was devoted to improving the detailed design through modularization, improving reliability and ruggedness; and by eliminating minor problems. Some functional additions were made to provide self checking and self disabling circuits, and access for maintenance and diagnostic equipment. In addition, field diagnostic equipment was designed and built.

Functional specifications for the ELU and CDU were prepared according to the requisites laid down in the BC Railways functional specification. Designs for the two units were completed according to the new specification and incorporated the following major enhancements.

2.1 ELU Design

a) The ELU was re-designed around a more powerful Zilog Z80 microprocessor as the central processing unit (CPU). This processor with its powerful and efficient instruciton set affords greater flexibility than the previous design using the RCA 1802 microprocessor. Furthermore, the Z80 is well supported by effective software development, testing and debugging aids. It is therefore easier to write, debug and maintain its software.

b) The new ELU processor board was designed to provide a set of general purpose, programmable serial and parallel ports. These would allow it to effectively interface with the CDU and other elements of the train subsystem; as well as external diagnostic equipment.

c) The transponder detection logic was separated from the main ELU processor board and placed on a dedicated Digitrac reader board, running under the control of its own microprocessor.

d) The display screen drive logic was removed from the ELU in favour of a serial interface to a cab display with on-board drive electronics. This method reduced even further the processing load on the CPU.

e) The ELU power supply unit was redesigned to provide the required on board stabilized DC voltage levels from a single external 12 VDC supply. This arrangement enables operation from existing supplies in either the locomotive or caboose, and eliminates the requirement for a 72 V supply in the caboose.

f) Self checking features were added to monitor the health of the CPU and other on-board equipment. The CPU monitor consisted of a watchdog timer circuit with the capability to power the system down in the event of a failure.

g) A reed relay output was added to allow for the application of train brakes, through the penalty service or emergency brake valves.

2.2 CDU Design

a) The CDU was redesigned around a new six line by 40 character gas-plasma technology display. A large amount of design effort was devoted to curing the readability problems experienced with the earlier display.

b) The display processing previously handled by the ELU was provided within the CDU by the addition of a dedicated Intel 8748 microprocessor and associated logic. The CDU processor was designed to interface with the ELU through an RS 232C port using serial ASCII formatted data.

c) The display screen drive-logic implementation was revised, to eliminate screen refresh timing problems that had caused a random flicker on the screen of the previous design. Particular attention was paid to the security of displayed data, such that the integrity of all displayed messages could be assured.

d) The CDU packaging concept was revised, following an ergonomics study of the locomotive cab and engineman position. Specific attention was paid to cutting down the amount of incident light on the display screen; to this end a louvred hood was designed for optional installation over the screen.

e) The CDU was totally modularized to enable its use in other applications, a particular concern here was ensuring interchangeability of the display screen itself. This will allow the future use of different format screens and more sophisticated display technologies as they become available.

2.3 Transponder Detection System Compatibility

The design of the Digitrac transponder detection system was reviewed to ensure compatibility with the modified ELU design. As a result of this review and the changes defined for the ELU, it was decided to re-design the reader as a stand alone board; capable of all transponder code retrieval tasks. This change would relieve the ELU's processor of the high loading associated with averaging and verifying the four digit transponder code.

The new reader board was designed around an Intel 8748 microprocessor with the necessary logic to interface with the ELU board and the interrogator coil unit. The board also incorporated a 12 V to 72 V converter to derive the necessary interrogator power supply.

The transponder units and interrogator coil units were both compatible with the new design and remained essentially unchanged from the previous system.

2.4 Equipment Production and Test

Three pre-production prototype sets of equipment were produced, each consisting of an ELU and CDU for installation in a locomotive; together with an ELU for installation in a caboose.

The necessary applications software was prepared according to the requirements laid down in the production equipment functional specification. Installation of the software in each of the units was followed by a period of testing and debugging, including:

- hardware and software system integration tests
- mechanical shock and vibration tests
- temperature tests
- humidity tests

Following the tests minor problems were discovered and correctional design changes specified and implemented. On successful completion of the development and system test phase, the units were released to BC Railway for installation in three of their locomotives and three of their cabooses.

A one month period of field testing was carried out to verify the designs, this testing was primarily aimed at proving the tracking performance of the improved ELU design. Tests were conducted in the following categories:

- transponder reporting
- odometer calibration
- communcations coverage
- train location

3. FIELD TEST RESULTS

3.1 Transponder Reporting

The results of the tests showed that the transponder reporting success rate had dropped to 96% from the 98% level experienced with the trial system. However, a packaging problem had been discovered with the transponders in place on the BC Railway infrastructure. In addition it was felt that the problems encountered could not be attributed to the design changes and were in fact problems that had not been solved following the trial system testing.

A program of further development and testing was carried out to identify the problems and define suitable solutions. A number of circuit modifications were made to the Digitrac reader and more significantly, the detection algorithm was modified to take better account of the statistical nature of the detection process. A further field test was carried out at BC Railway over an 18 day period. Upon completion of these tests, 1,262 transponders had been crossed and 1,261 had been successfully reported by the ELU, this translates to a success rate of 99.99%.

It was felt that the tests were too short, to unequivocably state that this success rate would prove to be accurate for a more statistical sample of about 10,000 crossings. However, the results were convincing enough to show that the success rate was at least 99%, and that the design changes were successful.

3.2 Odometer Calibration

The field tests showed that the odometer was potentially an accurate means for determining the precise location of trains. However, locomotive wheel wear had proven to be a limiting factor in maintaining the accuracy of the odometer and would have to be accounted for in the final system. With the implementation of the wheel wear correction factor in the ELU, it was felt that the odometer could be maintained to an accuracy of 0.1 mile over the whole Sub-division.

The tests also exposed problems with the chaining of the Sub-division which had caused the locations defining the position of certain transponders to be incorrect. As a result of the tests, these errors were corrected.

3.3 Communications Coverage

The communications coverage results confirmed those obtained during the trial system tests, when the observed net success rate was about 60-70%. This proved that the design changes to the ELU had not adversely affected the capability of the unit to maintain communications with central.

As a result of the tests, four potentially troublesome areas of weak coverage were defined, which would have to receive attention before implementation of the operational system.

3.4 Train Location

The results obtained from the tests showed that the train graph produced from the ELU location data gave an accurate representation of both current and projected train location. The graphs are more precise than those produced by CTC systems, by virture of the fine tracking capability of the system. A further advantage of the LIC graph is that it affords a continuous plot showing train identification, thereby eliminating a potential source of confusion.

4. CONCLUSIONS

Upon completion of the Project, the following results have been achieved:

a) The newly designed ELU and CDU were successfully system tested.

b) The ELU software is now much easier to develop, test and debug than with the previous system. The adoption of the Zilog Z80 microprocessor definitely improves the maintainability of the software and will make future changes easier to implement.

c) The CDU has a readable display under most ambient light conditions and the image does not flash. The new design provides greater security to displayed data.

d) The ELU and CDU have demonstrated their ability to operate within specifications under the arduous environmental conditions encountered in railway applications.

e) The field trials reveal that the transponder reporting success rate after initially dropping to 96%, has been improved to a level in excess of 99%.

f) The field trials show that while some problems remain to be solved, the prototype equipment as designed and built is suitable for implementation in an operational system on BC Railway.

5. RECOMMENDATIONS

As a result of this development project, it is recommended that the designs for the ELU and CDU be released for the production of a complete set of operational units.

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1. INTRODUCTION

This report covers a project to develop and test prototype train-on-board equipment for use in an operational location identification and control (LIC) system. The project was supported by the Government of Canada through the Transport Canada, Transportation Development Centre (TDC).

1.1 Background

Location Identification and Control (LIC) is a concept of railway traffic management which provides centralized control of train order and manual block territory. Computer equipment on board the trains and at the central office exchanges information via a digital radio communications link. The central office equipment collects location, speed, and status information from each train and shows train and track status on colour video displays. The dispatcher plans and executes train movements by computer interaction using the displays. Movement authorities are issued to each train, and appear in the locomotive cab in a prescribed plain language format on an illuminated display.

The LIC concept is significantly different from conventional methods of controlling train movements and is viewed generally by the railroad industry with interest, but scepticism. To gain acceptance in the industry, a plan for progressive development, evaluation and proving of the system was required. This was accomplished by a series of projects in which parts of the system were designed, implemented and field tested, prior to installing a fully operational system. The initial-system testing concentrated on the locomotive on-board computer, the display equipment and the data radio link. The next or trial-system was aimed at testing those improvements which were identified as being required, as well as evaluating the functions and capabilities of a dipatcher's computer and video display.

The trial system work was divided between Glenayre Electronics Ltd. and British Columbia Railway. Glenayre worked with the locomotive equipment, the track mounted location transponders and the radio-site control equipment. BC Railway were responsible for the radio communication link, the central office minicomputer and the colour video displays. During the trial period, control and separation of train movements were based on a dynamic block, whereby the system would maintain a separation of six miles engine to engine for following movements and would arrange meets where required. For movements without potential conflict, trains were run at maximum permitted track speed. The present speed limit and the next two speed changes with their distance ahead were the primary control instructions to the engineman. In addition, both speed and location odometer were also shown.

With the successful completion of the trial phase, a project was initiated by BC Railway to install an operational LIC system on their Squamish Sub-division. However, despite the extensive testing which had been carried out, the design of the LIC system electronic equipment had remained unchanged since early 1976. A number of problem areas had been identified which would have to be rectified for an operational system to be feasible. It was therefore decided to attack these problems by reviewing the design concepts of the system in anticipation of the operational installation.

1.2 Review of the LIC System Design

The initial task prior to beginning design work for the operational installation, was a comprehensive review of the concepts under which LIC would operate. This review was carried out in November 1978 by the LIC steering committee, consisting of personnel from both BC Railway and Glenayre Electronics. The primary objective of the committee was to refine the requirements, specifications and design of the LIC system, and produce a system capable of operational implementation on the Squamish Sub-division of BC Railway.

As a result of the review, the system design was significantly changed from that of the trial system. The most significant of these changes was the decision to adopt a fixed block scheme for controlling trains, as opposed to the dynamic moving block scheme used in the trial system. This decision was based upon the requirement for fail-safe operation; extensive field testing had proven this to be unattainable with the moving block system. As a result of the decision, the design of LIC could be based on proven concepts of fixed block control, such as centralized traffic control (CTC).

Also, in view of the requirement for the system to be fail-safe, the following functions were dropped from the System:

Speed Limits Displayed In The Cab: the system would revert to the existing system of wayside signs and speed bulletins.

Overspeed: as no display of the speed limit would be given, there is no way on-board the locomotive to detect overspeed

Illegal Entry and Train Outside Protection: there would be no provision to give protection on illegal entry. Illegal entry if detected would cause an alarm in the train dispatchers office. It will be the responsibility of the train dispatcher on what to do with the warning.

Computer Controlled Remote Braking: allowing the system to bring a train to a stop. With the removal of the illegal entry function and the difficulty of ensuring safety, it was decided to remove this facility.

Communications Failure: there would be no display in the engine; however, the dispatcher would be prompted by the flashing attempt to advance the train, on the track diagram display

The system defined by the steering committee for fixed block control of train movements required that five basic laws be obeyed:

1. Trains must have authority to pass control points in order to proceed.

2. Control Point authority and route gives train authority to move in one direction only.

3. Control Point authority and switching symbol allows movement in both directions but at restricted speed past a control point number(s) displayed.

4. Maintenance of way - has priority of track. Same as present Rule 42 (2). Engineman must have verbal authority from the maintenance of way foreman in charge, before he can pass either the boundary control point or enter work limits.

5. Rear Protection - there must be at least one control point between a train and a following train.

Control points demarking block limits would be established at each switch, and at intermediate points where the distance between sidings was large. The authorities to occupy blocks together with route information would be established by an explicit message to the cab display. The cab display would show the three most current authorities and a further three would be stored in the locomotive computer. To provide block clearance behind the train, a set of locomotive equipment, minus the cab display, was specified for installation in cabooses.

In addition to the constraints placed on the system by the change to fixed block operation; the results of trial-system testing had proven the following limitations in the system equipment:

- The RCA 1802 had severe disadvantages as a processor for the ELU. It is not well supported by development, debugging and maintenance tools.

- The CDU needed improvement: The display was not readable in bright daylight and the display tube flashed frequently.

- The transponder detection rate was 97-98%. This was not acceptable in railway applications.

To overcome these limiations and meet the requirements for the operational system design, the LIC engine logic unit (ELU) and cab display unit (CDU) required a significant amount of re-design. This project was concerned with the design, development and test work undertaken by Glenayre Electronics to meet these requirements.

An overview of the re-designed LIC system is given in Appendix A and it is recommended that this material is read next. This will give the reader a better understanding of how the development work fits in with the design of the operational system.

2. OBJECTIVES AND SCOPE

Glenayre Electronics was awarded a contract for further development of the LIC train borne equipment, to meet the requirements of the BC Railway implementation. This contract was known as the LIC pre-production prototype development project.

The objectives of this project were to:

a) Review the designs of the LIC electronic equipment in the light of the performance analysis which had been carried out and the field experience gained with the trial LIC system on B.C. Railway.

b) Produce an updated design for the locomotive mounted engine logic unit (ELU) and the cab display unit (CDU).

c) construct and test three complete sets of ELU and CDU pre-production prototype equipment.

A detailed statement of work is given in Appendix B.

3. ELU DEVELOPMENT

The purpose of this section is to report the design work done on the hardware and software of the LIC Engine Logic Unit. The project background and objectives are given first. The work done and results achieved are then described.

Upon completion of the previous phase of LIC development, the Engine Logic Unit (ELU) successfully performed the following functions:

- received and processed DPSK coded messages from Central
- transmitted DPSK coded messages to Central
- received transponder information through the interrogation interface
- maintained an internal odometer and speedometer
- displayed information for the engineman on the Cab Display Unit
- monitored the state of the ELU hardware and reported it to Central

Whereas the major ELU functions remained unchanged through development, the project had the following objectives:

- to review the design of the ELU and to incorporate design changes taking advantage of the latest advances in microprocessor technology, and simplify program generation
- to enhance the reliability of the unit and increase safety
- to improve maintainability and the facilities for testing the ELU

With these objectives in mind, the ELU hardware and software were re-designed, as further detailed in the remainder of this section. The re-designed ELU underwent rigorous testing, as described in sections 6 and 7.

3.1 ELU Hardware

With the experience gained from earlier development phases and with the objective of improving the ELU's maintenance, reliability and safety standards, the following aspects of the ELU hardware were reviewed and re-designed:

- ELU enclosure, physical layout and connectors
- power requirements
- central processing unit
- electrical interfaces
- hardware safety features
- diagnostics tools

3.1.1 Physical Layout and Connectors

The new ELU is contained on three double sided printed circuit boards of dimension 13" x 9.5". One board contains the Z-80A microprocessor, its memory, the data modem and all but the Digitrac external interfaces. The second board contains the Digitrac processor and assembly card. The third board is a multiple power supply: 5V, 12V, -12V for logic, and +72V for the Digitrac board. The boards are packaged in a cabinet designed to mount on a Glenayre model GL 9040 mounting base. There are four cabinet mounted connectors to the:

- interrogator coil unit
- cab display unit
- mounting base
- test port

The mounting base, in turn, is connected to the axle generator, to the forward/reverse selector, to the main power supply, to the status inputs, and to the radio.

Internally, there are detachable connectors between the three PC boards, transmitting power and Digitrac data.

The mechanical assembly of all equipment is ruggedly designed to endure operation on a train. Mounting is allowable in any orientation. Connectors are designed so that it is impossible to make incorrect external connections to any equipment.

Figure 1 is a photograph of the ELU.

3.1.2 Power Requirements

The ELU is operated from an external 12 V negative ground power supply. All necessary voltages (5 V for CMOS digital circuits, 12 V and -12 V for analog electronic ciorcuits and 72 V for the Interrogator Coil Unit) are generated within the ELU by a separate power converter module.

This power arrangement is convenient, since it enables operation of the ELU from existing 12 V supplies either in the locomotive or in the caboose. This eliminates the requirement for a special design of caboose ELU which would be necessary if the ELU were to be designed to operate from 72 VDC.

FIGURE 1

ELU Photograph

3.1.3 Central Processing Unit

The Zilog Z-80A microprocessor was selected as a Central Processing Unit (CPU) for the new ELU. The CPU memory is composed of up to 20K bytes of Read Only Memory (ROM) and 4 K bytes of Random Access Memory (RAM). The ROM is for permanent program storage and the RAM is for working space and temporary storage. The RAM has hardware to test the parity of every byte and inform the CPU when an error occurs.

All critical system timing functions are controlled by a single crystal oscillator operating at approximately 2.5 MHz.

The ELU software was logically re-specified and then written in Z-80 assembly language (see sub-section 3.2). The Z-80 has the following advantages over the RCA 1802 microprocessor used in the previous design:

- The Z-80 has more powerful and efficient programming istructions. It is therefore easier to generate and maintain Z-80 assembler programs.
- The Z-80 is better supported by program development, emulation and maintenance tools. It is therefore easier and more feasible to maintain, debug and upgrade the Z-80 programs.
- More test instruments are available for the Z-80 microprocessor

3.1.4 Electronic Interfaces

The various elelctronic interfaces were improved for better reliability, data security and flexibility. The ELU now interfaces to the following units:

a) Cab Display Unit: The CDU logic is now outside the ELU and is independently controlled by an 8748 microprocessor inside the CDU box. The ELU drives the CDU through an asynchronous serial port, RS-232C Compatible. The ELU-CDU transmission rate is 9600 baud, comprising 7 bit ASCII characters plus an odd parity bit, a start and a stop bit. The CDU is capable of indicating to the ELU that it has ceased to operate properly.

The removal of the CDU main logic from the ELU has the following advantages:

- the processor load on the Z-80 CPU is reduced, since the bulk of the display processing is done by the 8748 dedicated processor in the CDU box
- it allows for possible future replacement of the Burroughs 6 x 40 display with minimum changeover work. This adds flexibility to the LIC system.

b) Communications Modem: The DPSK encoder/decoder logic, as well as the communications modem, are part of the CPU circuit assembly. This logic waits for 100 milliseconds 'attack time' after actuating a TX-on relay, in order to allow the transmitter to come to full power. Only then is data transmitted via the modem interface.

The communications modem driver is asynchronous serial and is RS 232C compatible. Transmitted data are 8-bit characters with no parity, plus one start bit and one stop bit.

c) Digitrac Reader: The reader card assembly is on a separate PC board within the ELU. The Interrogator driver is asynchronous serial and is RS 232C compatible. Transponder data is received at a rate of 1200 baud, in 8-bit ASCII characters, with no parity bit, plus one start and one stop.

d) Axle Generator: Through the mounting base cable, the ELU interfaces to the axle generator on a locomotive. Pulses are accumulated in an 8-bit hardware counter. The axle generator driver reads the count and resets the counter at regular intervals to prevent overflow or loss of count. The ELU software uses this count to maintain a speedometer and an odometer.

e) Forward/Reverse/Stopped Sensor: Through the mounting base cable, the ELU interfaces to two sets of relay contacts. Closure of one set indicates that the train is moving 'Forward'. Closure of the other set indicates 'Reverse'. 'Stopped' is represented by opening of both sets. Closure of both sets indicates a hardware failure.

This arrangement is an improvement over the previous design in that 'Stopped' is indicated in addition to 'Forward' and 'Reverse'.

f) Mounting Base Interface: Through the mounting base interface cable, the ELU can read the hardwired 16-bit identity of the ELU.

3.1.5 Hardware Safety Features

In addition to rigorous software error checks (see sub-section 3.2), the new ELU electronics incorporates the following hardware safety features, (not included in the old ELU):

a) A watchdog timer system, comprising two independent hardware timers: the Interval timer and the Watchdog timer. The Interval timer has a shorter timing period than the Watchdog timer. The Interval timer must be serviced by the ELU software before the Watchdog timer expires. If it is not, the Watchdog timer perceives a major software fault. It then removes power from the Cab Display Unit and the radio. This prevents an unpredictable state, which might result from a software fault, and could cause a wrong transfer of information.

b) A Safety timer, used to shut down the transmitter when the microprocessor is too busy to do so. This timer is reset by the same signal which activates the 'Transmitter ON' switch. After the set time interval (which is longer than the longest possible output message time), the timer shuts off the 'TX-ON' switch.

c) Test circuitry for the self-disabling (fuse-blowing), axle pulse generator and UART loop-back functions.

d) All RAM memory is protected by the use of odd parity on each byte. If the parity is different on output than it was on input, an interrupt is generated and the CPU detects the error.

e) On power up, the CPU and communications circuits (UARTS) are reset for a period of time, ensuring that stable voltage levels are reached before normal operation begins.

3.1.6 Diagnostic Tools

The ELU has the capcity to drive a status indicator unit through a special purpose test connector. This is potentially useful for future field diagnostics of the ELU and, as such, will be a valuable maintenance tool. To-date, a status indicator unit for special applications has been built. In its present form, it can only be applied to laboratory ELU tests. Further hardware and software development is required before the Status Indicator can be applied to field maintenance and diagnostics.

3.2 ELU Software

This sub-section describes the development of software for the main CPU, the Zilog Z-80A. Software for the dedicated CDU processor and the Digitrac processor is described in sub-section 4.2 and section 5, respectively.

The ELU uses the AMX real-time operating system produced by Kadak Products Ltd. The source language is the Z-80 assembly language. All developed programs were properly annotated and documented.

The ELU software handles the following major functions in Location, Identification and Control of trains within a territory:

- maintaining an ELU's Odometer, Speedometer and Direction information
- maintaining a buffer of up to eight transponders recently detected by Digitrac, to assist in determining the train location
- driving the Cab Display Unit, to communicate with the engineman
- storing information on the Status, State and Mode of the ELU
- receiving messages from and transmitting messages to the Central Computer (see sub-section 3.3)
- maintaining high safety standards for the LIC system

The remainder of this sub-section further describes the specific ELU software features.

3.2.1 Odometer

Maintenance of the odometer is carried out in a similar fashion to that of the previous system. The ELU odometer must be calibrated before the train location is calculated. A calibration sequence is initiated by a locomotive when it receives a 'CALIBRATE' message from central. This message contains:

- the identity number of an approaching transponder
- the actual mileage of this transponder
- the heading of the train
- optional odometer correction factor information

When the engine crosses and detects the calibration transponder, the odometer is calibrated. From that point on, the odometer is further updated as follows:

- The number of axle generator pulses is read every half a second and the pulse counter is reset. the distance travelled is then calculated.

- The direction of travel (Forward or Reverse) is taken into account: the distance travelled is added to or subtracted from the odometer accordingly.

The odometer reading is calculated and displayed on the CDU to a precision of 0.1 mile, to a theoretical accuracy of ±0.05 miles. the odometer reading and the odometer constant can be further corrected by another 'CALIBRATE' message from central.

3.2.2 Speed and Direction of Travel

The ELU calculates the train speed by using a linear average of the last five seconds of odometer pulse counter data. A speed constant is stored. The speed is displayed on the CDU up to a full scale of 99.9 miles per hour, at ±1.5% accuracy at constant speed. It is displayed regardless of whether or not the odometer is calibrated

The direction of travel is identified by reading the state of the direction relays (see 3.1.4 Electronic Interfaces, sub-section (e) Forward/Reverse/Stopped/sensor).

3.2.3 Transponder Detection

The method of recording detected transponders is substantially improved by the design changes. Each time the Digitrac card assembly passes a transponder number to the CPU, a record is created, including the following information.

- transponder number. Elapsed time since the previous transponder was crossed, to a maximum of one hour.

- transponder location (as measured by the odometer), direction of travel, calibrate status and other status bits at detection time

If calibration is pending at detection time and the transponder number matches the expected one, the odometer is calibrated.

The transponder buffer may include up to eight transponder records in their order of detection; previous software allowed for only one record. Transponder records are reported on a first in first out basis to central and removed when central confirms with a REQUEST 2 message (see sub-section 3.3.1).

3.2.4 Cab Display Format

As explained in 3.1, the CPU drives the Cab Display Unit through an asynchronous serial RS-232C compatible port.

The Burroughs 6 x 40 display format was revised and is now divided into four regions, as described in Figure 2 and below:

- Region 1 displays the ELU speed, calculated as in 3.2.2
- Region 2 displays the current ELU odometer reading, calculated as in 3.2.1
- Region 3 displays an operating directive to the engineman, as explained in 3.2.5
- Region 4 displays up to three control point instructions from central, as explained in 3.2.6

3.2.5 Operating Directives

Five possible operating directives can be displayed in region 3 of the CDU. In order of priority, highest priority first, they are:

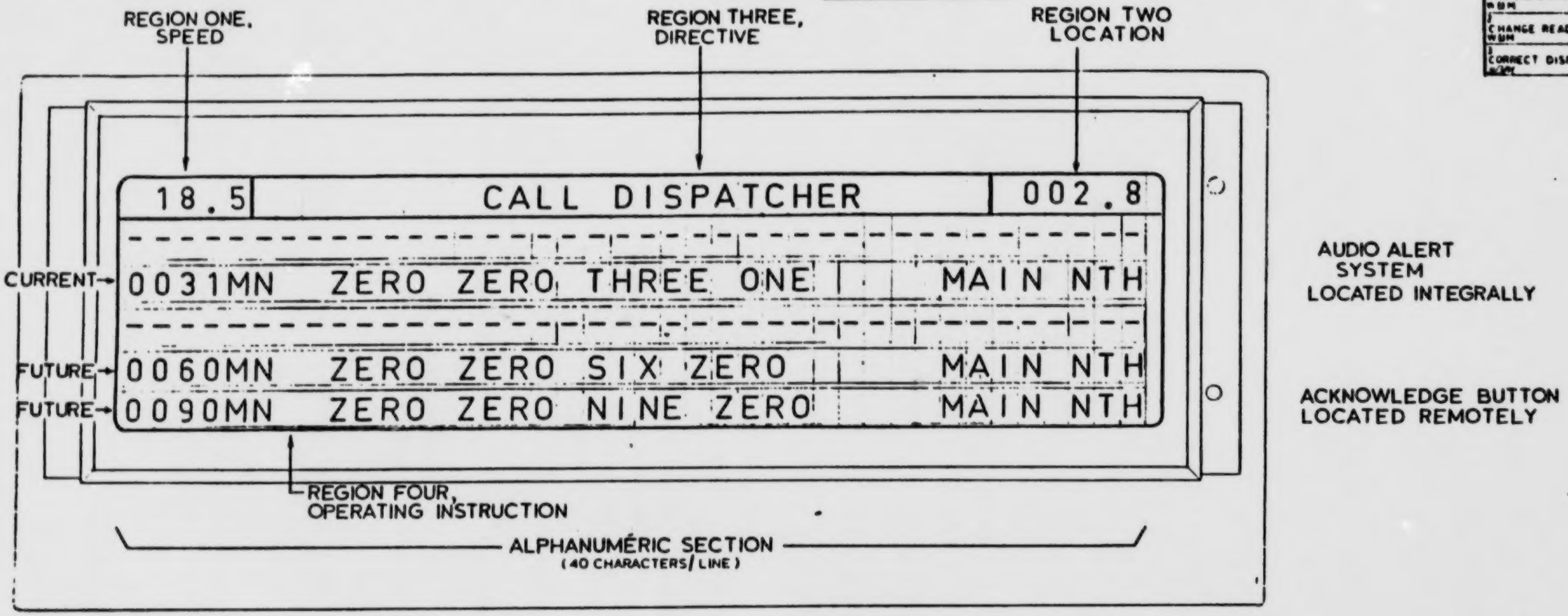
LIC SYSTEM FAULT
MANUAL OS
INSTRUCTION REMOVE
CALL DISPATCHER
ACK WHEN READY

Operating directives are displayed one at a time, according to their priority. When no directive exists, 'B.C. Railway' is displayed in region 3 together with the identification number of the software operating in the attached ELU. The operating directives are the result of the following conditions:

- 'LIC SYSTEM FAULT' is initiated by one or more of the following faults:
  - memory parity failure (wrong parity bit upon reading RAM)
  - interrogator failure (no 200 KHz signal generated)
  - odometer failure
  - odometer direction failure (both the 'Forward' & 'Reverse' relays are closed)
- 'MANUAL OS' is displayed when an instruction from central is received by the ELU to roll up its Control Point (CP) instruction buffer (MANUAL OS EXECUTE messages, see sub-section 3.3.4).
- 'INSTRUCTION REMOVE' is displayed when a message from central to remove the bottom CP instruction is received by the ELU (CP INST REMOVE EXECUTE message, see 3.3.4)

C-5205 3

REVISIONS	
1 CAB DISPLAY UNIT REVISED WBM	[illegible] CDM
2 CHANGE READ OUT WBM	[illegible] G T
3 CORRECT DISPLAY	82-07-06 DTL


REGION ONE, SPEED
REGION THREE, DIRECTIVE
REGION TWO LOCATION
18.5
CALL DISPATCHER
002.8
CURRENT
0031MN ZERO ZERO THREE ONE MAIN NTH
FUTURE
0060MN ZERO ZERO SIX ZERO MAIN NTH
FUTURE
0090MN ZERO ZERO NINE ZERO MAIN NTH
REGION FOUR, OPERATING INSTRUCTION
ALPHANUMÉRIC SECTION
(40 CHARACTERS/LINE)
AUDIO ALERT SYSTEM LOCATED INTEGRALLY
ACKNOWLEDGE BUTTON LOCATED REMOTELY

OTHER POSSIBLE DISPLAY FORMATS FOR REGION FOUR (OPERATING INSTRUCTION)

Abbreviated Inst.	Control Point	Routing	Direction
1056 SW	ONE ZERO FIVE SIX	----	SWG
1056RS	ONE ZERO FIVE SIX	RSTR	SOU
1056SN	ONE ZERO FIVE SIX	SIDE	NTH

FIGURE 2

TITLE:
L.I.C. CAB
DISPLAY
LAYOUT

DWG. NO. C-5205

BRITISH COLUMBIA RAILWAY
COMMUNICATIONS DEPT.

DR BY: W.B.M.	PLANNER G.T./DS
SCALE Full Size	CH'D:
DATE NOVEMBER 21,1979	

GL2025-021

- 'CALL DISPATCHER' is displayed when a message is received from central to call the dispatcher by voice radio (CALL DISPATCHER ON message, see 3.3.2)

- 'ACK WHEN READY' is displayed when a message from central is received by a locomotive ELU to execute a trip initialization as a head of train unit (ACK WHEN READY message, see 3.3.2)

All five directives require that the engineman press the 'ACKNOWLEDGE' button on the CDU. Upon doing so, the directive disappears. If more than one directive exists, the next higher priority directive is displayed. There is no provision for queueing directives at present.

3.2.6 Control Point Instructions

The LIC System ELU software enables central to send a sequence of up to six operating instructions to the engineman. As shown in Figure 2, up to the first three instructions are displayed on the Cab Display, region 4. The current operating instruction is displayed on line three of the display, and is highlighted by two lines of dashes on lines two and four. Future operating instructions are displayed in order on lines five and six.

As demonstrated in Figure 2, cognitive diversity is afforded by the displayed instructions. The instruction is displayed in alpha-numeric abbreviated form as well as spelled out alpha-numeric form. The engineman must inpsect the abbreviated and spelled out forms for consistency. This technique follows the procedures used in the issuing of train orders.

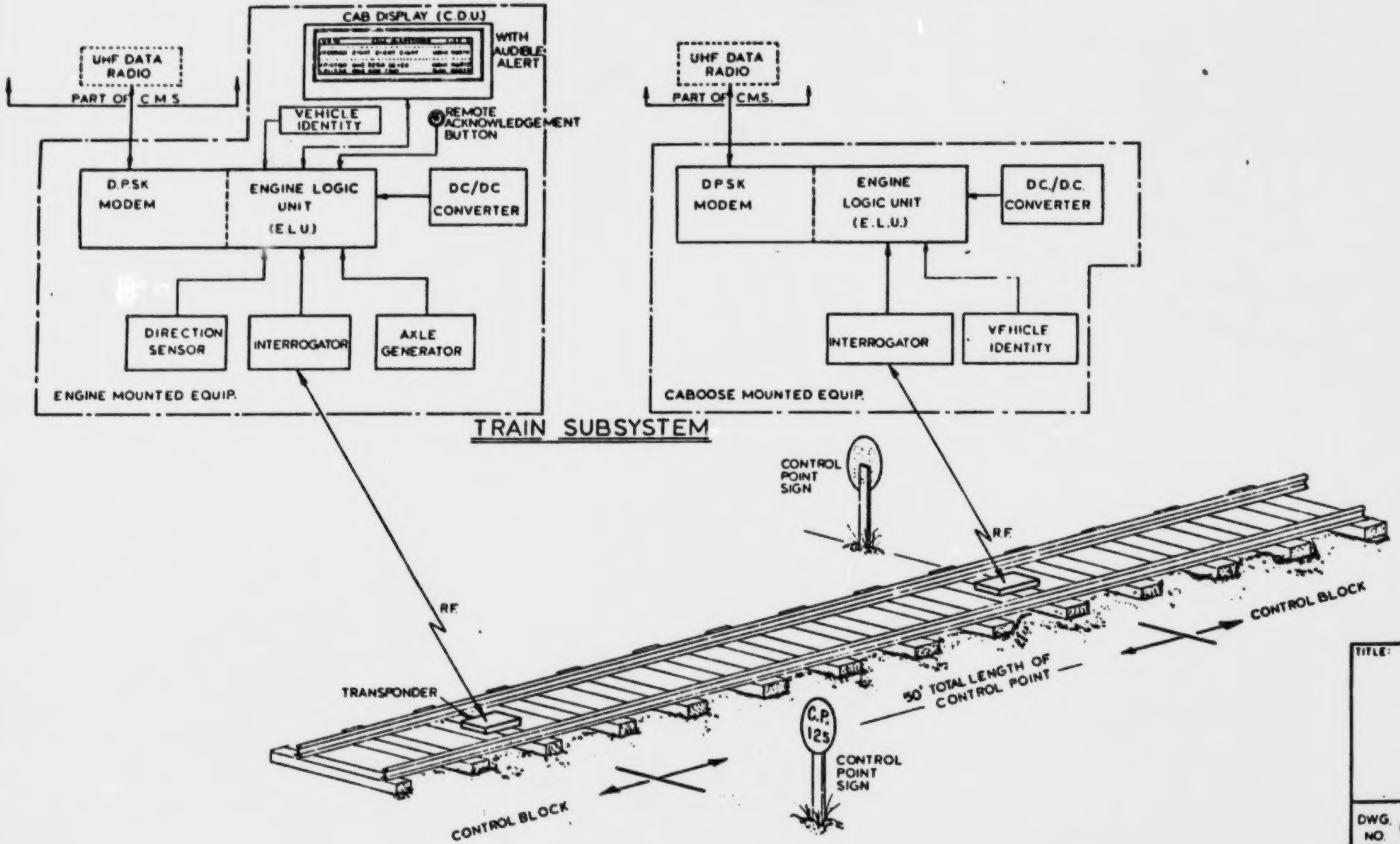
Every control point has an associated transponder pair, as shown in Figure 3. shortly after both transponders are crossed and detected, the CP Instructions are automatically rolled up. The oldest or current instruction is removed and the next instructions are moved up, both in the CP Instruction buffer and on the display.

Central can obtain information about the content of the CP Instruction buffer through the DUMP CP BUFFER message (see 3.3.1).

The most recently entered CP Instruction can be removed through use of the CP INST REMOVE message sequence between central and the ELU (see 3.3.4). If the instruction is displayed on the CDU, the engineman must press the CDU's Acknowledge button before the instruction is removed (an 'INSTRUCTION REMOVE' directive is displayed in this case, in the CDU's region 3. It is accompanied by an audible 'BEEP' to alert the engineman).

C-5201

REVISIONS
1 ADD VEHICLE I D 10 E L U 00/01/80
WBM CDN


UHF DATA RADIO
PART OF C.M.S.
CAB DISPLAY (C.D.U.)
WITH AUDIBLE ALERT
VEHICLE IDENTITY
REMOTE ACKNOWLEDGEMENT BUTTON
D.P.S.K MODEM
ENGINE LOGIC UNIT (E.L.U.)
DC/DC CONVERTER
DIRECTION SENSOR
INTERROGATOR
AXLE GENERATOR
ENGINE MOUNTED EQUIP.
UHF DATA RADIO
PART OF C.M.S.
DPSK MODEM
ENGINE LOGIC UNIT (E.L.U.)
DC./DC. CONVERTER
INTERROGATOR
VEHICLE IDENTITY
CABOOSE MOUNTED EQUIP.
TRAIN SUBSYSTEM
CONTROL POINT SIGN
R.F.
R.F.
TRANSPONDER
C.P. 125
CONTROL POINT SIGN
50' TOTAL LENGTH OF CONTROL POINT
CONTROL BLOCK
CONTROL BLOCK

CONTROL POINT LOCATION

FIGURE 3

TITLE: L.I.C. TRAIN SUBSYSTEM

DWG. NO. C-5201

BRITISH COLUMBIA RAILWAY

COMMUNICATIONS DEPT.

DR BY W B M	PLANNER GT/DS
SCALE N T S	CH'D:
DATE NOVEMBER 22, 1979	

All central-ELU messages pertaining to modification of the CP Instruction display or buffer are handled as vital tasks, since they are operating instructions to the engineman. Besides the BCH, parity and other checks, a double hand shaking is executed (i.e. Enable-Confirm-Execute sequence, see 3.3.4 to ensure that incorrect instructions are not communicated to the engineman).

3.2.7 Status Information

Based on rigorous hardware and software checks, the ELU maintains and reports to central, information on its mode, state and general status, as follows:

MODE:	COMM or NON COMM. The ELU enters the communicating mode when it receives a message addressed to it from central. It is non communicating if it has not received a message addressed to it from central for more than five minutes.

NOTE: An ELU commences a 'SPEAK UP' sequence if, in the NON COMM mode, a transponder is detected or unreported transponder data exists (see 3.3.3).

STATE:	CALibrated or UNCALibrated. In the CAL state, the ELU calculates and displays an odometer and speedometer. In the UNCAL state, the ELU calculates and displays only a speedometer.
STATUS FLAGS:	The ELU maintains (i.e. sets and resets) the following status flags:
POWER FAIL:	Set on 'Power On' or manual restart of the ELU
FAILURE DETECTED:	Set if either the memory parity fail flag, interrogator fail flag, odometer fail flag, odometer direction fail flag, or CDU fail flag is set
COMMUNCIATIONS FAIL:	Set if no communication from central was received for more than five minutes

- Engine Stopped, Forward or Reverse direction flags

Other Information:

The ELU maintains and, when requested, reports the following information to central:

- CP Instruction buffer entry counter and content
- train location, direction and speed (odometer and speedometer readings), as well as odometer correction factor
- detected transponder numbers, locations (as measured by the odometer), time since last crossing and other associated flags

3.2.8 Software Safety Features

The ELU and CDU handle the important functions of determining and reporting vehicle location and identification to the central computer. The ELU and CDU also handle vital control functions, such as presenting operating instructions to the engineman. As such, the new ELU must be designed following fail-safe principles, i.e. any equipment failure will not result in the engineman receiving a false operating instruction. The following software safety features contribute to fail-safe operation of the system:

a) Every communications message includes five cyclic check bits and one parity bit per 32 bits. This code is checked by the ELU software and provides high immunity to single bit and burst errors.

b) Every operating instruction entails an Enable, Confirm and Execute sequence of central-ELU messages, before it is actually stored and displayed. A similar sequence applies to removal of an operating instruction from the buffer and to removal of an operating instruction from the buffer and display. The ELU software ensures that the proper sequences are followed.

c) An operating instruction received by the ELU contains redundant information comprising a binary form and a corresponding encoded transformation of the same information. The ELU software checks both forms for consistency.

d) The display of an operating instruction is redundant, as shown in Figure 3. It comprises a numeric abbreviated form (e.g. 0031MN) followed by a plain-language description of the same instruction (e.g. ZERO ZERO THREE ONE MAIN NORTH). The engineman must check for consistency between the two formats of a displayed operating instruction, before acting upon it.

e) The ELU software reads the instruction display buffer in the CDU and compares it with the ELU stored information.

f) Central can read the content of the CP Instruction buffer through a DUMP CP BUFFER message to the ELU.

g) Transponder reports are sent to central. In turn, central echoes the transponder number back to the ELU for verification.

In addition to the software safety features, hardware safety features were also implemented in the new ELU, as described in sub-section 3.1.5.

3.3 ELU-Central Communications

As described in Section 2, data communication between the Engine Logic Units (ELUs) and the Data Collection Processor (DCP) at the Central office is accomplished by the LIC Communications Sub-system. The ELU interfaces to the Communications Sub-system via a serial asynchronous data channel. The data is DPSK coded and transmitted at a nominal rate of 300 baud.

Data communications messages consist of one or more blocks of four eight bit characters (bytes). The first three characters in a block are information characters and the fourth includes the following eight code bits:

- one header bit (= 1 for only the first block in a message)
- one end bit (=1 for only the last block in a message)
- five Bose-Chaudhuri-Hocquenghem (BCH) error detection bits
- one odd parity bit

The length of a message is determined by its type, as explained further, to a maximum of seven blocks. The first two characters in the first block always include a 16-bit BCH coded ELU identity number. The third character in the first block is the code of the message type.

The remainder of this section explains the 33 ELU-central message types. Based on the function that messages are intended to fulfill, they are organized into four major categories, as shown in Figure 4:

a) Messages through which central requests specific information from a specific ELU

b) Messages through which central initiates certain dispatcher - engineman transactions or calibration operations

c) Messages through which the ELU reports to central

d) Message through which central and the ELU communicate operating instructions to the engineman

a) Status Requests (3.3.1)

* REQUEST 1
* REQUEST 2
CALIBRATE STATUS
DUMP CP BUFFER
* DIAGNOSTIC

b) Test, Calibration and Directive Transactions (3.3.2)

ACK WHEN READY (locomotive)
* ACK IMMEDIATE (caboose)
CALIBRATE
CALL DISPATCHER ON
CALL DISPATCHER OFF
* TEST

c) ELU Reports (3.3.3)

* STATUS 1
* STATUS 2
STATUS 3
STATUS 4
* STATUS 5
* BCH ERROR
* SYNTAX ERROR
* CONTEXT ERROR
* SPEAK UP

d) Operating Instructions (3.3.4)

CP INST
CP INST CONFIRM
CP INST EXECUTE
CP INST REMOVE
CP INST REMOVE CONFIRM
CP INST REMOVE EXECUTE
MANUAL OS
MANUAL OS CONFIRM
MANUAL OS EXECUTE
* FORCED FAIL
* FORCED FAIL CONFIRM
* FORCED FAIL EXECUTE
* ABORT

NOTE: Only messages marked with * are used by a caboose ELU.

FIGURE 4 ELU-Central Message Types

An end-of-train ELU does not have an axle generator or a CDU, and its software is capable of handling only a subset of the locomotive messages, as indicated in Figure 4.

The remainder of this sub-section describes specific messages, grouped within their categories.

3.3.1 Status Request Messages

The central dispatcher can inquire about and confirm ELU status and information, through the following message types:

REQUEST 1:	This is the normal polling message which central sends to every ELU in the LIC territory every 30 seconds. The message is one block long. The expected reply is STATUS 1 (indicating train speed, location and general status information, see 3.3.3 or STATUS 2 (if the ELU is also reporting a detected transponder).
REQUEST 2:	This is central's response to a STATUS 2 message from an ELU. Its purpose is to confirm that the detected transponder data was received by central and to allow the ELU to delete the transponder record from its buffer. If another transponder record exists, the ELU reports with another STATUS 2 message. Otherwise, STATUS 1 is sent to central.
CALIBRATE STATUS:	This message is central's request for the ELU's current odometer calibration parameters. the expected ELU reply is a STATUS 3 message, see 3.3.3.
DUMP CP BUFFER:	This message is central's request for the content of the Operating Instructions Buffer. The expected ELU reply is a STATUS 4 message, see 3.3.3.
DIAGNOSTIC:	When received by an ELU from central, this message causes the ELU to transmit diagnostic status information to central, via a STATUS 5 message, see 3.3.3.

3.3.2 Test, Calibration and directive Transactions

The central dispatcher can request that the ELU perform test, calibration or directive transaction operations, by use of the following message types:

ACK WHEN READY:	When received by a locomotive ELU, this message causes the ELU to execute a trip initialization sequence, display an 'ACK WHEN READY' directive in region 3 of the CDU, and send a STATUS 1 message back to central.
ACK IMMEDIATE:	This message is sent from central to an End-of-Train ELU to execute a trip initialization sequence. The expected reponse is a STATUS 1 message.
CALIBRATE:	This message is sent from central to an ELU to aid in calibrating its odmeter. It contains a transponder number that the train is expected to cross and its location in decimiles, as well as calibration control bits. The expected reply from the ELU is a STATUS 1 message.
CALL DISPATCHER ON:	This message from central to an ELU requests that the engineman calls the Central dispatcher by voice radio. When received, it results in an appropriate directive on the CDU's region 3, as well as a STATUS 1 message back to central.
CALL DISPATCHER OFF:	Message from central to an ELU instructs the ELU to turn off the Call Dispatcher directive on the CDU's region 3, the expected reply is a STATUS 1 message back to central, see 3.3.3.
TEST:	When received by an ELU from central, this message causes the ELU to execute a test cycle and then to transmit a STATUS 1 message to central. The results of this test are obtained by the DIAGNOSTIC message.

3.3.3 ELU Reports

Except for the four Confirm messages, see 3.3.4, the ELU messages to central are described next. If the received message has no errors, the ELU sends one of the following message types to central:

STATUS 1: This message is the ELU's response to central's REQUEST 1 and REQUEST 2 (if no transponder information is in the buffer), ACK WHEN READY (locomotive), ACK IMMEDIATE (end of train), CALIBRATE, CALL DISPATCHER ON, CALL DISPATCHER OFF, TEST, ABORT, CP INST EXECUTE, MANUAL OS EXECUTE, CP INST REMOVE EXECUTE and FORCED FAIL EXECUTE. STATUS 1 incudes the location and speed of the train, as well as ELU status flags. Central is not required to respond to STATUS 1.

STATUS 2: This message is the ELU's response to REQUEST 1 or REQUEST 2, if more transponder data exists in the buffer (REQUEST 2 deletes one record). It contains the same information as STATUS 1 as well as information on the transponder detected. Upon receipt of a STATUS 2 message, central is required to send a REQUEST 2 message to the ELU.

STATUS 3: This message is the ELU's response to central's CALIBRATE STATUS message. It contains odometer parameters and calibration flags. No response message is required from central.

STATUS 4: This message is the ELU's response to central's DUMP CP BUFFER message. It contains the current and future operating instructions stored in the isntruction buffer. No response message from central is required.

STATUS 5: This message is the ELU's response to central's DIAGNOSTIC message. It includes specific failure bits (memory fail, interrogator fail, etc) as well as other diagnostic information. No response message from central is required.

The following message types are ELU responses and indicate a problem in the received message from central. Messages with errors are not implemented by the ELU.

BCH ERROR:	This message is the ELU's response to any message from central, if there was a block check error in one of its blocks.
SYNTAX ERROR:	This message is transmitted by the ELU to notify central that there was an error in the content of one of the blocks of a received message.
CONTEXT ERROR:	This message is transmitted to notify central that the message just received is not appropriate for the present condition of the ELU. For example: a 'DUMP CP BUFFER' message received while a CP Instruction Remove Sequence is still be processed, see Ref: 1, Sub-section 4.6.
SPEAK UP:	This message is sent by the ELU to central, if the ELU is in the NON COMMunicating mode (i.e. not communicated with central for more than five minutes) and it either has: - transponder records in its buffer - has just detected a transponder The purpose of the SPEAK UP message is to re-instate ELU communication with central. It is repeated at specified intervals until a polling message, REQUEST 1, is received from central.

3.3.4 Operating Instructions

Operating instructions are displayed on the Cab Display Unit's region 4. The CP Instruction buffer contains from zero to six instructions. Extreme care has been taken in the ELU software design to meet the fail-safe objective for operating instructions. In order to ensure that the correct CP Instruction is communicated to the engineman, the following Enable-Confirm-Execute sequence has been implemented for all four Operating Messages:

a) Central sends an operating instruction e.g. CP INST (Enable) message

b) The ELU responds by confirming the message it received and its content, through a Confirm message to central, e.g. CP INST CONFIRM

c) Central compares the confirmed data versus the original data. If they match, the dispatcher may send an Execute message, with the same data, e.g. CP INST EXECUTE.

d) The ELU confirms the newly received data versus the data received by the original Enable message. If they match, the Operating Instruction is executed, and a STATUS 1 message sent to central.

e) Before sending an Execute message, the dispatcher may cancel the Operating Instruction by sending an ABORT message instead of Execute.

This Enable-Confirm-Execute sequence applies to the following types of Operating Instructions: CP INST, CP INST REMOVE, MANUAL OS and FORCED FAIL.

Each of these messages has the associated Confirm and Execute messages:

CP INST:	This message is transmitted to an ELU by central, in order to store a Control Point Instruction. It contains the Binary Code Decimal (BCD) representation of the Control Point number at which the instruction is effective, the numbers of both transponders identifying the Contol Point, the direction and route part of the CP Instruction, see Figure 3.

	The expected ELU response is a CP INST CONFIRM message to central. Central may respond by an ABORT message or CP INST EXECUTE. If the latter was chosen, the CP Instruction is queued in its buffer, as explained in 3.2 (f). If two or less instructions are displayed on the CDU, the new CP Instruction is also displayed.
CP INST REMOVE:	This message is transmitted by central to an ELU, in order to cause removal of the last CP Instruction from the CP Instruction buffer. the ELU responds by sending a CP INST REMOVE CONFIRM message to central. The dispatcher may respond by an ABORT message or a CP INST REMOVE EXECUTE message. If the latter is chosen and the CP Instruction is not displayed, it is simply removed from its buffer. If the CP Instruction is displayed, a directive 'INSTRUCTION REMOVE' is displayed in region 3 of the CDU. The engineman is required to press the CDU's Acknowledge button, in order to actually remove the CP Instruction.
MANUAL OS:	This message is received by an ELU when central requests that the ELU manually rolls up its CP Instruction buffer. This is done in order to recover from a missed Control Point transponder. The ELU, in turn, sends a MANUAL OS CONFIRM message to central. The central dispatcher may respond with an ABORT message or a MANUAL OS EXECUTE message. If the later was chosen, a 'MANUAL OS' directive is displayed on the CDU's region 3. Before a manual roll-up occurs, the engineman must press the CDU's Acknowledge button.
FORCED FAIL:	This message is received by an ELU when central requests that the ELU turn off its CDU and radio. The ELU, in turn, sends a FORCED FAIL CONFIRM to central. The central dispatcher may respond with an ABORT message or with a FORCED FAIL EXECUTE. When received by the ELU, the latter message causes the blowing of a special fuse which powers the radio's 'transmitter-on' relay and the CDU's power relays.

4. CDU DEVELOPMENT

The purpose of this section is to report the design work done on the hardware and software of the Cab Display Unit (CDU). The project background and objectives are given first. The work done and results achieved are then described.

The trial-system used the Burroughs 6 line by 40 character gas plasma display and the display logic was controlled by the ELU's Central Processing Unit. Upon completion of the trial system test-phase, the following problems were evident:

- display was not easily readable in bright ambient light
- display was not stable and flashed while its data was changing
- display was difficult to test without being connected to an operating ELU

In the pre-production version of the CDU, these problems had to be corrected. The CDU re-design phase had the following objectives:

- provide greater security to displayed data
- ensure that the display is readable at all times
- allow independent testing of the CDU

As further described in this section, these objectives were met through:

- having an independent Intel 8748 processor and its associated logic, control the display from within the CDU to provide greater data security

- simplifying the ELU-CDU connector, so that the CDU can be tested independently on a keyboard connected through an RS 232C compatible input

- installing an adjustable louvred hood and a dimmer switch, to ensure that the display is easily readable under all ambient light conditions

A photograph of the CDU mounted in a locomotive cab is shown in Figure 5.

4.1 CDU Hardware

With the experience gained from previous system testing and with the objectives of improving the displayed data security and readability, the following aspects of the CDU hardware were reviewed and re-designed:

- mechanical layout and engineman interfaces
- internal electronics and interfaces

4.1.1 Mechanical Layout

The CDU is enclosed in a rugged box, suitable for operation on a train. Externally, it has the following interfaces:

A connector for both the ELU and a remote 'Acknowledge' button, incorporating the following functions:

a) ELU-CDU/Communication -

The electrical interface complies with EIA RS 232C standards for data interchange circuits. The ELU transmits characters at a high rate of 9600 baud.

b) Electrical Power

This connection provides the 12 VDC, necessary to operate the CDU from the ELU power supply board.

c) Acknowledge Button

The acknowledge (ACK) button is the enginemans sole means of input to the ELU. The Acknowledge button is a robust, heavy duty design, highly resistant to mechanical failure. Closure of its relay contacts is recognized by the CDU, which in turn, switches off the sonalert and sends a control-E character to the ELU.

d) Dimmer Switch

A two-position switch is fitted on the CDU. It is used to dim or brighten the display, for viewing in subdued artificial light or in a brightly sunlit cab, respectively.

e) 6 x 40 Display Panel

A Burroughs gas plasma 6 lines x 40 characters display panel is used to communicate to the engineman. This display is controlled by the CDU's electronics. Its high voltages are supplied by the CDU's internal power supply, operated from 12 VDC.

f) Louvred Hood

An adjustable mechanical louvred hood is installed, to improve the readability of the display in bright sunlight.

g) Sonalert

An audible sonalert is fitted on the CDU. It is activated when directives requiring the engineman's attention are displayed. The sonalert is switched off automatically after 2 ±0.5 seconds have elapsed. The frequency of the sonalert expressly avoids the range 2800-3000 Hz, to avoid confusion with other equipment in the cab.

4.1.2 Internal Electronics

The CDU electronics consists of three printed circuit boards and internal interfaces. The three boards perform the following main functions:

a) Power Supply Board

This board receives the ELU input 12 VDC and generates the necessary high voltages for the display elements.

b) Display Board

This board is directly connected to and controls the gas plasma display elements.

c) Processor Board

This board contains the ROM-programmed special purpose Intel 8748 microprocessor and its associated electronic components. As further explained in Section 4.2, this processor accepts ASCII characters from, and sends characters to the ELU. It also governs the timing and display of characters on the 6 x 40 Burroughs display panel.

The three PC boards are interconnected and interface to the following:

- ELU and Acknowledge button connector
- Sonalert
- Display panel

4.2 CDU Software

This sub-section describes the software developed for the special purpose CDU processor. The Intel 8748 chip has internal Read Only Memory (ROM) and Random Access Memory (RAM). The CDU software was written in 8748 assembler.

The procedure to program an 8748 chip is as follows:

- the 8748 chip's ROM is erased, using ultra-violet light
- up to 1 K bytes of program object code is generated
- the object code is loaded into the chip's ROM, using Intel's software development system

The CDU software handles the following functions of the display unit:

- receiving ASCII control and alpha-numeric characters from the ELU, through the RS 232C asynchronous serial communications link
- acting upon characters received from the ELU, as explained further
- transmitting ASCII characters to the ELU through the same link
- reading the status of the Acknowledge button and sending a control character to the ELU if it was pressed
- activating the 2 ±0.5 seconds sonalert when a Control G character is received from the ELU
- switching off and de-activating the sonalert after the Acknowledge button was pressed
- controlling the 240 (6 x 40) display character positions

ASCII characters sent from the ELU which the CDU acts upon are:

- text characters to be displayed at specific locations on the available six display lines
- control characters to determine hardware/software control mode, to determine the position of the cursor and to provide data security

The CDU software effectively governs the timing of character display and thereby maintains a secure, stable and reliable display.

The CDU software is easy to test by using a simple keyboard at the ELU input. ASCII characters transmitted though the keyboard are of the same format as the characters sent from the ELU. This is a substantial improvement in the CDU over the previous design.

4.3 Reliability of CDU

The LIC System Cab Display Unit specification, required a reliability figure for the CDU hardware.

Handbook MIL HDBK 217B, C and some in-house information was used as reference.

Summary of failure rates per 10^6 hrs:

Logic board assembly	6.339
Power board assembly	11.678
Burroughs display assembly (50.000 hrs)	20.000
TOTAL:	38.02

Estimated mean time between failures:

MTBF = $1/38.02 \times 10^6 = 26{,}300$ hrs

1095 days (24 hrs/day)

3 years (365 days/year)

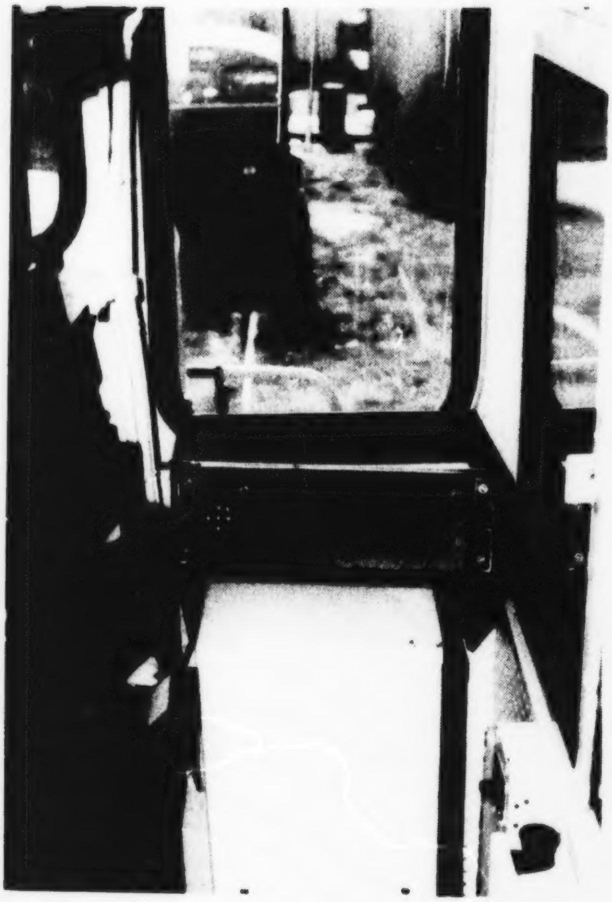


FIGURE 5

CDU MOUNTED IN A LOCOMOTIVE

5. DIGITRAC DEVELOPMENT

The purpose of this section is to report the design work on the hardware and software of the LIC prototype Digitrac system. The project bakcground and objectives are given first. The work done and results achieved are then described.

5.1 Trial System Digitrac Configuration

a) Passive transponders: installed on the railroad track. The transponders are activated by a 200 KHz signal from the Interrogator Coil Unit (ICU). In turn, they generate a continuous string of DPSK modulated serial data frames on a 25 KHz sinewave data carrier. This string is transmitted back to the ICU by a 27 MHz RF transmitter. The transponders were tested immersed in water, in adverse whether conditions and in temperatures of -40°C to +70°C. Accurate transponder data transfers were obtained at train speeds of 0 to over 100 miles per hour.

b) Interrogators (ICU's): installed on the underside of the vehicle, parallel to the track, as shown in Figure 7. The ICU's are rugged and hermetically sealed units, suitable for operation on trains. An ICU receives its power from the ELU. It continuously generates and transmits a low power electromagnetic field at 200 KHz. Upon entering this field, a transponder's circuitry is energized, and it transmits a modulated signal in the HF radio band as previously described. This signal is picked up by a receiving antenna located in the interrogator, the interrogator passes the decoded signal to the ELU.

c) A dedicated processor PC board: part of the ELU electronics. LIC, at this point in time utilized the RCA 1802 microprocessor in the interrogation interface. Software was written to average 256 transponder data frames, to perform code safety checks, and to identify the 4 digit transponder number. The interrogation interface then interrupted the main Central Processing Unit and reported the received transponder number.

Upon completion of the LIC trial system project, the following observations were made about the transponder detection system:

- The system provided the ELU with transponder data, useful for odometer calibration. Detected transponder numbers were reported to central, thus verifying the location of a train.
- The transponder detection rate was 97-98%, which is not sufficient for railway applications.

5.2 Prototype System Digitrac Configuration

The transponders and interrogator coil units remained essentially unchanged from the trial system, as shown in Fig. 7. The transponders remained in place on the trackbed for the duration of the development work, a fact which would later cause problems (see Part 7). The three interrogators used in the trial system were complemented by a further three manufactured units. The addition of these units was necessitated by the design change which now required Digitrac equipment in both the locomotive and caboose.

5.2.1 Hardware Development

With the changes made to the ELU in terms of packaging, central processor and interfacing, it was necessary to re-design the Digitrac reader board.

The new ELU package did not utilize the earlier rack and edge connector configuration due to problems with connector reliability in the locomotive environment. The Digitrac PC card was configured to virutally the same dimensions as the main ELU board. This would allow mounting one above the other, with connectorized jumper cables.

The main development to the reader board was the adoption of a dedicated Intel 8748 microprocessor to handle all transponder code retrieval tasks. This contrasts with the earlier design where the code was captured by the reader board, but passed to the ELU processor for averaging.

The Intel 8748 was chosen because of its single chip processing capabilities. The following functions are contained in the single 40 pin package:

- 8 Bit CPU
- 1 K x 8 EPROM Program Memory
- 64 x 8 RAM Data Memory
- 27 I/O Lines
- 8 Bit Timer/Event Counter

The instruction set is extensive for a machine of its size and is tailored to be straightforward and very efficient in its use of program memory. The capability to handle arithmetic operations in both binary and BCD as well as handling single bit operation ensures efficient programming. The CPU interfaces with an Intel 8251 universal synchronous/asynchronous receiver transmitter (USART) to provide the necessary ports for the interrogator and ELU board.

The adoption of this dedicated processor configuration would relieve the ELU's processor of the high loading associated with averaging and verifying the four digit transponder code. Also in keeping with the system modularization concept, it would allow the Digitrac board to be used as a stand alone transponder reader without the ELU.

The receiver and interrogator drive electronics was implemented as per the previous design, with minor detail changes.

The final enhancement to the reader board was the inclusion of a 12 V to 72 V DC converter to provide the necessary interrogator power supply. This feature would ensure that all LIC train-borne equipment could be run from a single 12 V supply.

5.2.2 Software Development

With the change from the RCA 1802 to the Intel 8748 microprocessor, a rewrite of the detection software was necessary. This involved a change from one assembly language to that of the new processor. In addition, as already explained, all transponder code retrieval tasks would now be handled by the dedicated processor. This required the combination of the followig tasks from the trial system:

task 1: Handled by Digitrac board, retrieval of transponder code from interrogator

task 1: Handled by ELU, averaging and verification of code received from Digitrac board

The implementation of each of these was handled in exactly the same manner by the new system, but under the control of the single dedicated processor. Thus, the detection algorithm was still based upon averaging up to 256 transponder data frames.

5.2.3 Further Development

Subsequent testing of the new digitrac reader revealed that certain problems had been carried over from the previous system. In addition, a number of new problems had been created, the sum effect causing a lower transponder capture rate then with the trial system.

The implications of this problem were discovered during the prototype tracking period when the capture rate was found to be only 96% on average. Further development work was carried out on the Digitrac reader to rectify this problem and is described in detail in Part 9. After implementation of these changes, the capture rate was seen to have risen to above the 99% level.

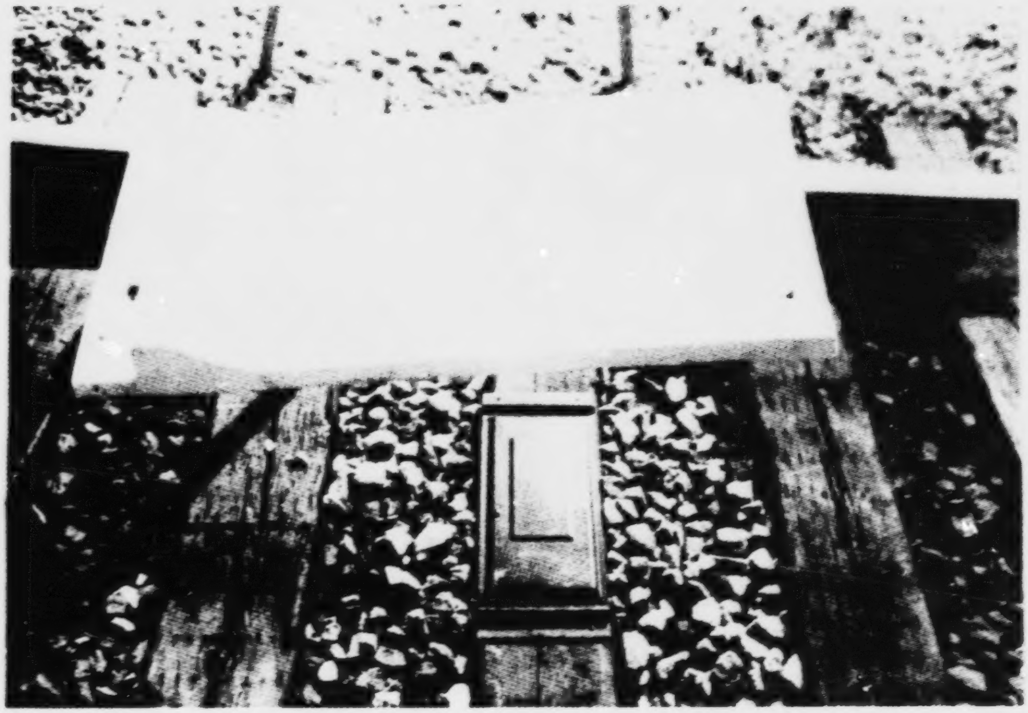


FIGURE 6

DIGITRAC HARDWARE

6. FABRICATION AND UNIT TEST

In accordance with the contract requirements, three pre-production sets of equipment were manufactured. Each of the three sets consisted of:

- locomotive ELU model GL 6580A with mounting base, interfaces and cables
- caboose ELU model GL 6580A as above, but excluding cab display cable
- cab display unit model GL 6527 for installation in the locomotive only

In addition, two interrogators model GL 6215 were added to each set, one for the locomotive and one for the caboose. These were already available as a result of the trial LIC system equipment manufacture.

Following manufacture, the ELU's and CDU's were bench tested to ensure that assembly was in accordance with the design. The tests carried out consisted of:

1. Visual inspection of wiring, PCBs and general assembly
2. All switch and strap selectable options were set to the application defined positions
3. Basic parameter and function test included:

    - power supply level check and adjustment
    - check all frequencies, clock rates, input/output levels and where necessary, waveforms. If necessary, calibrate and fit select on test components.
    - measure unit power consumption and check power supply over-voltage and current limit where applicable

Following these basic tests, a program of more rigorous design qualification testing was embarked upon. Insofar as the ELU was concerned, these tests proved problematical and the majority of ELU testing was carried out in the field trials. On the other hand, all of the CDU testing was carried out in-house, as there was no means of testing out cab display control in the field at that point in time.

The remainder of this section will briefly deal with the in-house ELU hardware and software tests and will deal with the corresponding CDU tests in more detail. The major phase of Digitrac testing was carried out in the field and will be described along with the ELU field tests in the next section.

6.1 ELU Design Tests

6.1.1 ELU Hardware Tests

Special purpose software was written to enable rigorous testing of the ELU hardware, to conform with its environmental specifications (as outlined in reference 3). The ELU hardware was tested under adverse temperature (0-50°C), humidity, shock and virbration (EIA RS 374 standard) conditions.

The ELU test software was loaded into 4 K bytes of ROM. This ROM was installed in the ELU, replacing the operational software. The test software continually monitored ELU hardware and output hardware status information through the ELU test port. Through this port, the ELU hardware status information was sent to a special purpose Status Indicator Box.

The following aspects of the ELU hardware were tested and monitored for potential failure:

- interrupt lines of the modem, DIGITRAC interface and CDU interface
- random access memory
- read only memory
- hardware watchdog timer
- 'transmitter on' relay
- vehicle identity number
- other hardware aspects

Problems detected during these hardware tests were corrected. The ELU now operates according to its specification.

6.1.2 ELU Software and Integration Tests

The ELU software was lab tested with a complete locomotive equipment set. The laboratory apparatus included an ELU, CDU, interrogator and a pulse generator (replacing the locomotive axle generator).

The ELU communicated directly (without a radio) to another unit with the central Data Collection Processor's software. This apparatus represented a full LIC System, wihtout the Communications Sub-system. Transponders were waved in front of the Interrogator to simulate movement along the railroad track.

The following system functions were tested:

- polling of a train by central
- reporting of a train's location, speed, travel direction and status to central
- calibration of a train's odometer
- maintenance of a train's odometer and speedometer
- requesting a train's diagnostic information
- detection and reporting of transponders by a train
- displaying central's Operating Instructions on the CDU, by following the Enable-Confirm-Execute sequence
- automatic and manual roll over of operating instructions
- removing Operating Instructions from the CP buffer and inquiring about the buffer content
- remotely removing power to the CDU and radio, through use of the 'Forced Fail' message sequence

After installation of the three prototype units on the BC Rail trains, further tests were carried out (see Part 7). Minor problems detected with LIC equipment were corrected. Successive tests of the system proved it operational. After completion of the tests, B.C. Railway released the design for the production of the remaining units required for their operational implementation.

6.2 CDU Design Tests

6.2.1 CDU Hardware Tests

The Cab Display Unit was subjected to rigorous tests, in order to comply with its environmental specifications, see reference 2. For most tests, the success criterion was whether or not the CDU could properly respond to a Power Up Reset command during the test. In order to pass the test, the CDU had to produce a screen of asterisks upon Power Up Reset.

6.2.1.1 Temperature Test on Model 6527 Cab Display Unit

A temperature test was conducted on the CDU to verify the specifications.

The CDU was complete with all parts in place. Eight thermocouple wires were attached to different places inside the Unit and brought out through the sonalert openings in the front bezel. The CDU was placed in the center of the temperature chamber with the mounting bracket on a piece of plywood. Two MS type connectors were attached to the CDU with cables for power and signalling routed to the outside of the chamber.

A CRT terminal and power supply were hooked up to the cables as well as a DIM and ACK switch. After verification of proper operation, the temperature chamber was started.

Two tests were made:

1. CDU operating and temperature set for -10°, 0, +20°, +40°, +50°C.

2. CDU not operating, and temperature set for -10°C. At -10°C, the CDU was switched ON and the temperature chamber switched OFF.

At each set point, the proper operation of the CDU was verified by checking all control functions.

Test Results:

Cab Display Unit 6527	S/N	100	
Power Supply LAMBDA	S/N	GL 185	12 V 20 Amp
CRT Terminal VOLKER CRAIG Odd Parity, Transparent ON	S/N	2065 173	9600 Bd
Dig. Thermometer FLUKE 2166A	S/N	718024	
Multimeter Beckman 3020	S/N	GL 160	

Supply Voltage +11.95 volt
Supply Current 2.38 Amp Full Screen 2.45 Amp at -10°C
2.07 Amp Blank Screen

This was fairly constant over the temperature range.

Thermocouples were lcoated in the following positions:

Thermocouple No.	Location
1	Top of 8748 microprocessor
2	Power Supply Unit (PSU) heatsink
3	Burroughs display (top)
4	Top/middle chassis.
6	Air temp adj PSU LV switching transistor
7	Bracket HV transformer
8	Outside top of housing
10	Bottom chassis

The results recorded were as follows:

Time 29 June	Set Point in °C	Measured Dry Bulb	Thermocouple #								Ambient #5, #9
			1	2	3	4	6	7	8	10	
11.00	-10		37	34	40	33	33	35	29	32	24
11.35	-10	-10	25	07	29	08	11	26	00	03	28
12.00	-10	-10	21	05	25	05	08	21	-02	01	29
12.30	-10	-10	18	03	22	03	05	17	-03	-01	30
12.40	0										
14.00	0	0	26	11	30	12	13	25	06	08	31
15.00	+20	+20	41	28	46	29	29	40	24	26	32
16.00	+40	+40	59	47	63	47	47	58	43	45	35
17.00	+50	+50	68	56	72	57	57	67	53	55	35
CDU switched OFF after check out.											
30 June											
8.15	-40										
9.30	-10		-02	-05	-02	-05	-04	00	-07	-06	27
10.00	-10	-10	-06	-15	-06	-13	-11	-05	-21	-15	28
CDU switched ON.											
			-07	-16	-07	-15	-12	-06	-20	-17	
Temp. Chamber turned OFF.											
			-04	-08	-01	-11	-08	-04	-01	-09	

From the results obtained, it was concluded that the CDU met the requirements and that the test was successful.

6.2.1.2 Humidity Test on the Model 6527 Cab Display Unit

The CDU was subjected to a humidity test as required by the LIC System CDU specification GL2390-002. The specification calls for a humidity test as per EIA-RS374 standards.

The upper limit of the Temperature-Humidity envelope was chosen as the worst case VIZ. 30°C at 90% Relative Humidity.

The test was carried out in the Thermotron Climatic Test chamber at Glenayre.

Relative Humidity is determined by the temperature of the 'dry' and the 'wet bulb' thermocouple in the test chamber. For a 90% RH at 30°C, the dry bulb temperature setting is 30°C (86°F), the wet bulb temperature has to be 2.5°F less or 89.5°F.

The CDU was placed inside the test chamber, hooked up to an external car battery with a switch for the power supply. With the CDU not operating and the dry and wet bulb set points at 86°F and 83.5°F, the test chamber was run for eight hours. With intervals of approximately one hour, the CDU was switched on and checked for the proper Power Up Reset sequence.

Test Results:

Electrical:	The unit operated normally each time power was applied although the Reset hold off was getting progressively longer with time. Printed circuit board leakage was thought to be the cause and a different value for the hold off network was chosen.
Mechanical:	The black button-head machine screws holding the bezel and display assembly in the housing showed signs of oxidation. They were replaced with stainless steel pan-head screws.

6.2.1.3 Mechanical Test of CDU Model 6527

The CDU was subjected to a mechanical shock and vibration test as required by the LIC System CDU Specification GL2390-002.

The specification calls for shock and vibration tests as per EIA RS374 standards.

The tests were carried out at Wagner Engineering. The unit met and exceeded all specifications.

The test consists of four parts with the test parameters of each point as shown in the tabulated test data.

Test 1

A shock test on the Mechanical Mock-up, serial number 103 without its mounting bracket to determine:

a) the need for IC device retaining clips
b) the maximum g force that the display tube can withstand in this mounting configuration

IC's dislodging from their sockets constitute a failure. These IC's will be taped down in Working Unit serial number 100. Test b) results in a number that is not to be exceeded in the test with the Working Unit.

Test 2

A vibration test on the Working Unit with sunvisor installed, with and without the mounting bracket. First, a trial run with the unit not operating, finally with power applied.

Unit shall be kept at resonance for two minutes in Y, X and Z axis.

A unit not properly responding to the Power Up Reset command during the test constitutes a failure.

Test 3

A shock test on the Working Unit with its proper mounting bracket installed.

Mechanical parts are allowed to be permanently deflected, but the unit should respond to the Reset after the test.

Test 4

The Display Unit removed from its housing shall be vibrated in X, Y and Z axis. Observe excessive deflection of components, boards, wiring, etc.

General Test Parameters

Vibration tests shall be in X, Y and Z axis over the frequency range 10 to 30 Hz with a double .015" half sine displacement, then 30 Hz to 60 Hz with a double .0075" half sine displacement.

The shock test shall be executed for the Y axis first, as this is the normal operating position, next in X axis, then in Z axis.

The g forces shall be progressively increased: 5 g for Y, x, Z; 10 g for Y, X, Z, etc

The g force curve shall be a half sinewave with a duration of 11 milliseconds and peaks of 5 g, 10 g, etc. Weight of the Working Unit S/N 100 with bracket is 6.8 kg (15 lbs). Weight of sunvisor is 2 kg (4.4 lbs).

Test Results:

Test 1 (04 November):

CDU 6527 S/N 103 - Without mounting bracket.

Tester in MANUAL, brake in OFF position, impact on loosely draped cotton rag between table and anvil.

Air Pressure in PSI	Table Height in Inch	Acceleration in Peak g			Duration in mSec	Number of Impacts
		Y Axis	X Axis	Z Axis		
8	5	6	6	8	9.5	—
15	5	16	12	15	8	2 in X,
18/20	5	20	23	23	6.5 + 2	5 in X, 4 in Z
22	5	30	25	30	7 + 1	2 in Z
22	5	-	-	40	7 + 1	—

a) No failures occurred after a total of 22 impacts.
b) No IC came loose from its socket.
c) The display tube did not break at 40 g in Z axis.

Test 2 (05 November):

CDU 6527 S/N 100 - With mounting bracket.

Unit operating during test. Vibration unit could not be set up for constant displacement. A constant acceleration was chosen instead. Acceleration 1.5 g.

	Y Axis	X Axis	Z Axis
Frequency Sweep in Hz	5.5-60-5.5	5.5-60-5.5	5.5-60-5.5
Displacement	See Graph - Figure 7		
Duration of Sweep	5 min + 1 sweep with sunvisor	5 min	5 min

Without Mounting Bracket

Frequency Sweep in Hz	5.5-60-5.5	5.5-60-5.5	5.5-60-5.5
Displacement	See Graph - Figure 7		
Duration of Six Sweeps	30 min	30 min	30 min

a) No resonance was detected in X, Y or Z axis with either setup.
b) No failure occurred during or after the test.

Test 3 (04 November):

CDU 6527 S/N 100 - With mounting bracket.

Unit operating during test.

Air Pressure in PSI	Table Height in Inch	Acceleration in Peak g			Duration in mSec	Number of Impacts
		Y Axis	X Axis	Z Axis		
8	5	5	6	5	9	—
15	5	10	13	12	9	—
20	5	24	22	28	8.5	2 in Y, 3 in Z
20	5	23	21	33	8.5	2 in X, 3 in Z

a) No failure occurred and unit operated normal after a total of 18 impacts.

Test 4 (05 November):

CDU 6527 S/N 100 - Display Unit without housing.

Unit operating during test. Acceleration 3 g.

	Y Axis	X Axis	Z Axis
Frequency Sweep in Hz	5.5-150-5.5	5.5-150-5.5	5.5-150-5.5
Resonance Frequency	No Resonance		
Duration of One Sweep	7 min	7 min	7 min

a. No resonance occurred below 150 Hz.
b. No component failed, unit operated normally.
c. A manual sweep revealed a mild resonance of electrolytic capacitor cluster C103, 104, 105 at 160 Hz.

No action will be taken as these capacitors are held together as a triplet with RTV.

Nearing the completion of the test, a soft failure in the RAM chip U10 showed up. 20 Hex deforms to 30 Hex, 2 AH shows as 3 AH. This single bit error is internal to the chip and cannot be attributed to the mechanical testing. The chip was replaced.

6.2.2 CDU Software Tests

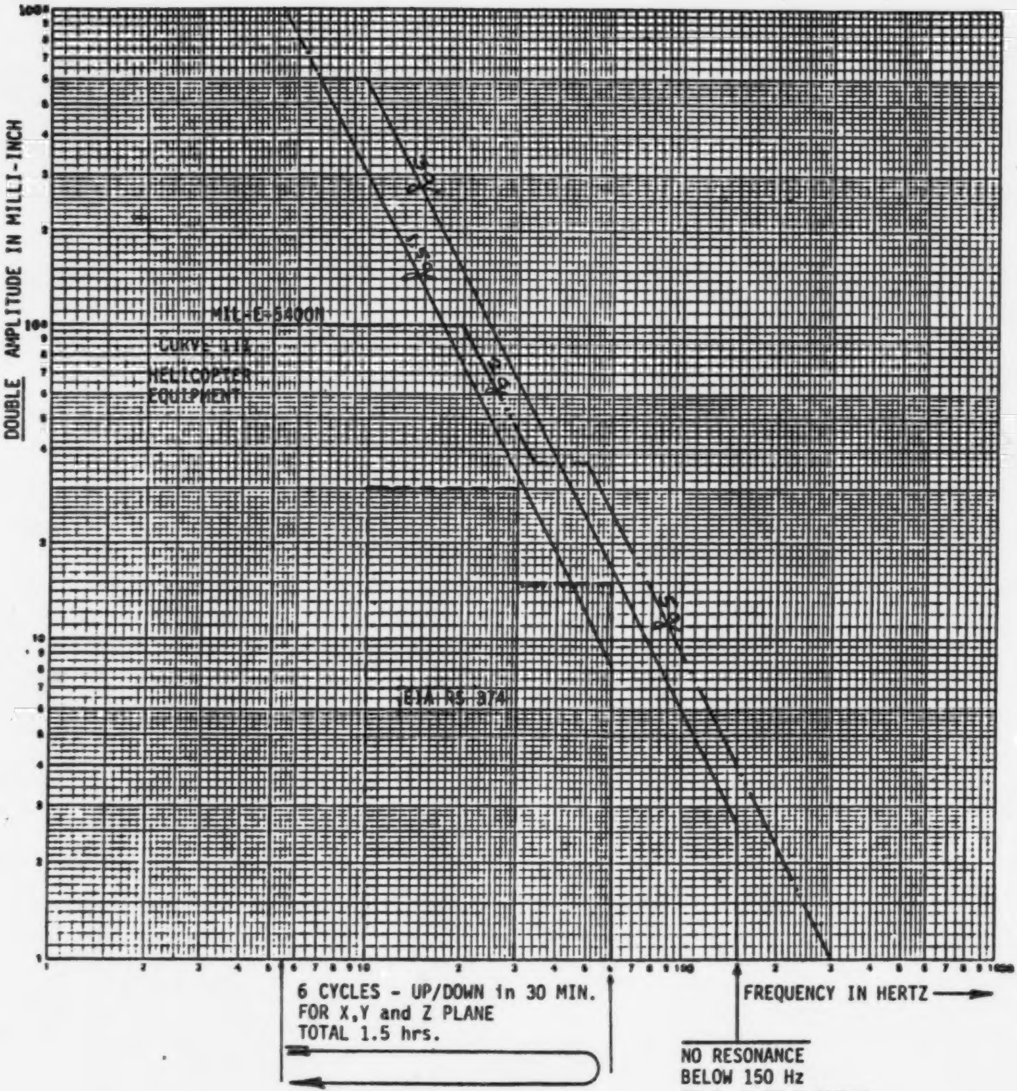
The CDU software was tested, independently of the ELU. Characters were transmitted to it by an external keyboard through the asynchronous serial RS-232C compatible port. Erronious as well as correct character strings were sent to ensure maximum immunity of the unit to errors. Test inputs were keyboard entered characters and the Acknowledge button. Test outputs were the 6 x 40 display, the sonalert and the characters returned from the CDU via the RS-232 compatible port.

The software test results were as follows;

- characters appeared at the correct display locations, as determined by a correct sequence of control and alpha-numeric characters, see reference 3
- no erroneous display occurred as a result of irregular input character sequences
- sonalert was activated for two seconds as a result of Control-G input character
- sonalert was switched off upon pressing the Acknowledge button
- Control-E was sent back upon pressing the Acknowledge button
- characters were echoed back via the RS-232C port.

figure 7

VIBRATION TEST - CAB DISPLAY UNIT 6527



6 CYCLES - UP/DOWN in 30 MIN.
FOR X,Y and Z PLANE
TOTAL 1.5 hrs.

NO RESONANCE
BELOW 150 Hz
IN X, Y OR Z PLANE

7. ELU BASIC TRACKING TESTS

The Basic tracking tests completed in November, 1981, involved six pre-production Engine Logic Units and a single pre-production DCP. The ELU's were installed on three engines and three cabooses which were to be monitored over a period of seven days i.e. for a total of 42 unit trips.

The Basic tracking tests were conducted between 02 October and 04 November, 1981. The units initially involved were engines 705, 710 and 717 and cabooses 1871, 1872 and 1875. Engine 717 was withdrawn from service temporarily part way through the tests, and its ELU was transferred to Engine 706. Results are presented for all four engines.

The Basic tracking test plan stipulated that "the one weeks successful demonstration will be fulilled after each equipped unit has been tracked for seven consecutive trips over the Squamish Subdivision". It did not prove possible to meet this requirement with all units in a reasonable length of time. A variety of reasons were involved.

Some of the difficulties were quite unrelated to LIC operation. The temporary loss of Engine 717 has been mentioned already. Similarly, the Railway was not always able to retain LIC-equipped cabooses on the Squamish Sub-division which meant excessive delays between valid trips for tracking purposes.

Problems with the LIC equipment itself meant that many of the trips undertaken were incomplete in terms of the test. In several cases, apparent failure of a caboose logic unit was traced to a power shutdown at the main supply switch. (CLU power was subsequently routed to bypass the switch). Other caboose equipment problems were not as easily solved.

As a result, the number of successful caboose trips in the Basic tracking period did not meet the test plan requirements.

Finally, the number of trips and specific trip dates for a given unit are not always the same for every tracking function. This apparent inconsistency arises because the time required for manual extraction of all tracking data from the DCP events record was not available during the test period. In each area of Basic tracking; however, the total number of trips reported meets or exceeds the total number (6 x 7 = 42) stipulated in the test plan.

7.1 Transponder Reporting

BC Railway conducted the transponder reporting tests and provided the statistical results. If the criterion of 99.8% successful reporting was not met, it was to be the responsibility of Glenayre Electronics to determine the reaons(s). If the problem could be traced to BC Railway's communications system, then the Railway was to assume responsibility. If BC Railway was satisfied that any problem discovered could be corrected during the rework phase, then the tests were to be considered complete.

7.1.1 Results

Initial tets were carried out with a total of 194 transponders, but the results were not acceptable. Investigation showed that 72 of the transponders had become inoperative, largely as the result of a packaging defect which allowed the ingress of water. The 72 defective transponders were lifted and returned to Glenayre for repackaging. Further tests were conducted with 122 known functional transponders. Of these, 81 would be encountered on a normal trip from North Vancouver to Lillooet. The information was retrieved manually and transcribed onto a separate report for each unit. Figure 8 is an example of such a report (see Appendix D for further examples).

Table 7-1 summarizes the results of the Basic tracking transponder reporting tests. The reporting rate taken over all units and all trips in Basic tracking was 96.0%. The best record was returned by Engine 705, which successfully reported 99.4% of all transponders encountered.

Unit No.	Trips Compltd	Transponders Encountered	Transponders Reported	Transponders Missed	%
705	7	576	573	3	99.4
706	9	534	668	66	91.0
710	12	999	959	40	95.9
717	8	654	647	7	98.9
1871	1	81	78	3	96.2
1872	7	568	560	8	98.5
1875	11	901	851	50	94.4
TOTAL:	55	4.513	4.336	177	96.0

TABLE 7-1 BASIC TRACKING TRANSPONDER SUMMARY

figure 8

UNIT NO. 710
DATE ______

STATION		MILEAGE	TRANSP. Nº												
N. VANCOUVER		24		F	F	F	F	F	F	F	F	F	F	F	F
AMBLESIDE		30		01	02	03	06	07	09	14	15	16	17	18	19
				N	S	N	S	N	N	S	N	S	N	S	N
MILEAGE		50	0290	X	X	X	X	X	X	X	X	X	X	X	X
		60	0220	X	X	X	X	X	X	X	X	X	X	X	X
			0247	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		100	0046	X	X	X	X	X	X	X	X	X	X	X	X
			0256	X	X	X	X	X	X	X	X	X	X	X	X
HORSESHOE BAY	M	116													
	S		0138												
	A		0279	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		130	0050	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		150													
MILEAGE		165													
BRUNSWICK	A	185													
	M														
	S		0147	X											
	S	200	0231	X											
	M														
	A		0265	[illegible]	[illegible]	X	X	X	X	X	[illegible]	X	[illegible]	X	[illegible]
MILEAGE		230	0054	X	X	X	X	X	X	X	X	X	X	X	X
PORTEAU	A	253	0055	X	X	X	X	X	X	X	X	X	X	X	X
	M		0056	X	X	X	X	X	X	X	X	X	X	X	X
	S		0057												
	S	265	0293												
	M		0059	X	X	X	X	X	X	X	X	X	X	X	X
	A		0060	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		300													
			0249	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		320													

BASIC TRACKING TRANSPONDER REPORT

None of the units met the Test Plan criterion of 99.8% reporting. the overall level of performance is not as good as that observed during the prototype test phase. It should be remembered that the earlier tests were less extensive and were carried out under more closely controlled conditions.

7.1.2 Problems

As previously mentioned, a packaging problem had been found which resulted in the ingress of water. While the transponders known to be suffering from this fault had been repackaged, it was felt that others may be similarly affected. At this time, there was a considerable body of opinion that felt this was the total cause of the degradation in transponder reporting success.

In the process of carrying out transponder tests, some unexplainable properties of the detection process had manifest themselves. The most significant of these was the tendency for transponders to only reliably report when at the extremes of the interrogator L..F. field. The problem was thought to lie in one of two areas:

- digitrac reader board receiver electronics
- digitrac detection algorithm software

7.1.3 Evaluation

Initial transponder reporting with the six pre-production ELU's could only be described as disappointing. However, it was felt that the problems were not new and were present when the trial system tests were conducted. The drop in reported transponder success rate can only be attributed to the known packaging problem and the fact that the earlier tests were less extensive.

It was decided that the problems were more complex than at first thought and that further effort would have to be directed to their solution. The outcome of this work warrants further discussion than given here and is thus covered separately in Part 8.

7.2 Odometer Calibration

The odometer calibration tests were carried out by BC Railway and the resulting DCP events printer records were transcribed and graphed by Railway personnel. In the event of unsatisfactory performance, it was the responsibility of Glenayre Electronics to determine the cause and correct. Additional tests were to be conducted until the calibrate feature proved satisfactory.

7.2.1 Results

The odometer calibration results were plotted as graphs of odometer error versus true mileage. On northward trips, the odometer error was computed as the mileage reported at a transponder crossing minus the true mileage. To maintain uniformity in the graphs, the error on southward trips was taken as true minus reported mileage. For odometer calibration purposes, 'true' transponder mileage refers to the transponder mileage as stored in the DCP track model. The original calibration records are represented in graphical form in Appendix E.

7.2.2 Problems

Three significant features may be observed in these odometer calibration graphs:

1. The magnitude of the odmeter error increased steadily for each unit as it traversed the subdivision. For a given engine, the average absolute slope of the graphs is reasonably consistent for both northward and southward trips, but it is not necessarily the same from one unit to the next.

2. All of the graphs show essentially the same deviation at certain locations. For example, the peak at mileage 26.5 occurs on every graph.

3. Some graphs show additional unexplained irregularities, and some show small offsets between lines (not due to recalibration).

7.2.3 Evaluation

The odmeter calibration feature is potentially a means for accurate determination of train location, but its performance requires further improvement for it to be included in an operational system. It was felt, however, that the problems involved were all understood and would be corrected in short order. Specifically, it was concluded that:

1. Small departures from nominal wheel size on each unit have a significant effect on odometer accuracy. The graphs suggest that a factor to correct for wheel wear can be measured by means of the ELU odometer and applied to subsequent readings to achieve greater accuracy. The results for Engine 706 are particularly interesting. This unit was equipped with new wheelsets at the time of the tests, and the average slope of its calibration plots is near zero. The system should in the future, take advantage of the full calibration procedure which takes the wheel wear factor into account.

2. Closer examination of the lines plotted for a single unit shows that the small departures from the straight line of average slope are not, for the most part, due to random variation or hardware error. Consider, for example, the calibration graphs for Engine 705. Note that the three southward trips produced plots of virtually identical profile. The three northward trips also gave similar profiles, although the lines are offset as the result of recalibration. Moreover, when one graph is inverted and superimposed upon the other, all six lies coincide closely.

   The consistency of these errors could be explained only if the track model locations of certain transponders were incorrect. Upon investigation, it was found that there were errors in the original chaining of the sub-division, which made it necessary either to resurvey all of the trackage or to modify the DCP track model. Given the time and manpower requirements for a full survey, BC Railway decided to generate a new track model using the ELU odometer on the V-10 track vehicle to ascertain the actual location of each control point.

   The accuracy of the V-10's odometer was confirmed by a number of runs over a measured mile, yielding an average value of 1.02 mile. All subsequent readings were corrected by this factor.

   The V-10 then made four complete trips over the Squamish Subdivision, stopping precisely at each control point to record its location on the DCP printer. The mean value for each control point was used in an updated track model.

3. In view of the erratic readings caused by wheelslip or other unknown factors, the ELU should be able to do a simple calibration at any transponder when the error in the reported mileage reaches a certain limit.

7.3 Communications Coverage

BC Railway was responsible for conducting the tests and for providing the finished statistical reports. In the event of unsatisfactory communications performance, it was also the Railway's responsibility to determine the cause.

7.3.1 Results

Table 7-2 summarizes the Basic tracking communications coverage results. The table shows the average communications performance for each unit (ratio of valid ELU responses received to DCP transmissions made) over the number of trips completed by that unit. Appendix F contains the individual trip reports for each unit tested under Basic tracking.

For the locomotives, trip communications performance ranged from a low of 34% to a high of 78%. In general, however, between half and two-thirds of all message exchanges were successfully completed on a given trip. As was mentioned earlier, it was difficult to get a sufficient number of complete caboose trips during basic tracking.

It is not possible at this point to recover the information necessary to report the total number of speakups per trip or to generate individual site coverage statistics for Basic tracking. Each unit spoke up upon entering the LIC territory, but no count of speakups was derived from the DCP record.

Unit No.	Transmissions by DCP	Responses From ELU	Successes Rate (%)
705	12219	8234	67
706	2169	1190	55
710	1504	898	60
717	2015	694	34
TOTAL:	17907	11016	61.5

TABLE 7-2 BASIC TRACKING COMMUNICATIONS SUMMARY (ENGINES)

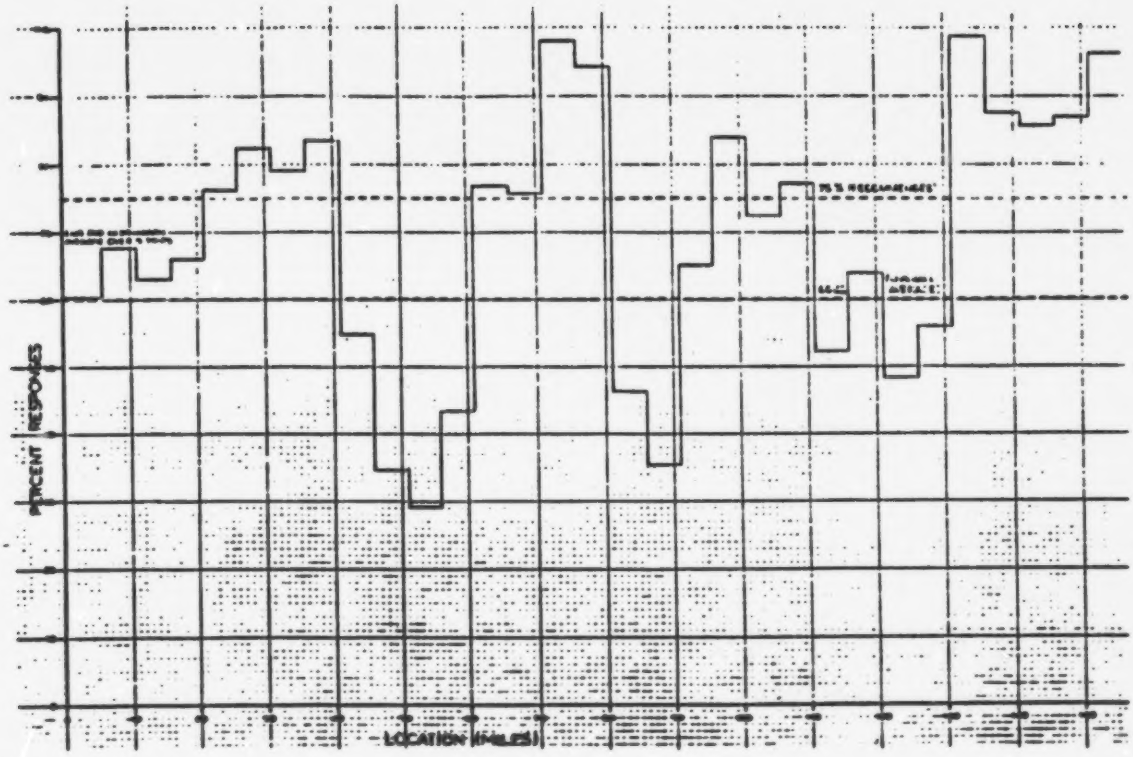
7.3.2 Problems

Examination of the trip reports (Appendix F) suggests that there are certain specific areas of weaker coverage. Figure 9 is a graphical representation of typical communications performance by location. The graph shows the percentage of DCP transmission for which a valid ELU response was received on each five-mile interval of track. The data in this case have been averaged over five northward trips of Engine 710. The chart illustrates clearly the known weak areas at MP 11-20 (Horseshoe Bay), 44-61 (Cheakamus Canyon), 86-94 (Pemberton), and 112-125 (Darcy).

7.3.3 Evaluation

The communications coverage results confirm those obtained during the prototype tests, when the observed net success rate was about 60-70%. It was felt, that the average reported success rate was adequate for LIC tracking purposes. Additional confirmation came from the system load test (Appendix H) in which all six units were placed on one train and tracked successfully through the weak areas.

fig. 9



COMMUNICATIONS PERFORMANCE - BASIC TRACKING

7.4 Train Location

It was the responsibility of the BC Railway to gather the DCP train graphs and to monitor the performance of this function. In the event that the train location results were not satisfactory, it was Glenayre's responsibility to determine why and make the necessary corrections.

7.4.1 Results

The DCP train graph function performed as specified. Figure 10 illustrates a typical DCP train graph (see Appendix G for further examples).

The graph correctly uses a unique symbol e.g. pr705....*, to identify each unit or Provisional Train. Train locations are shown to the nearest two miles. Where more than one train is at approximately the same mileage, a special 'multiple trains' symbol is printed. The graph illustrated started at 1601 on 07 October, 1981 and shows a meet between PR717 and PR1875 at approximately mileage 114 (Birken).

7.4.2 Problems

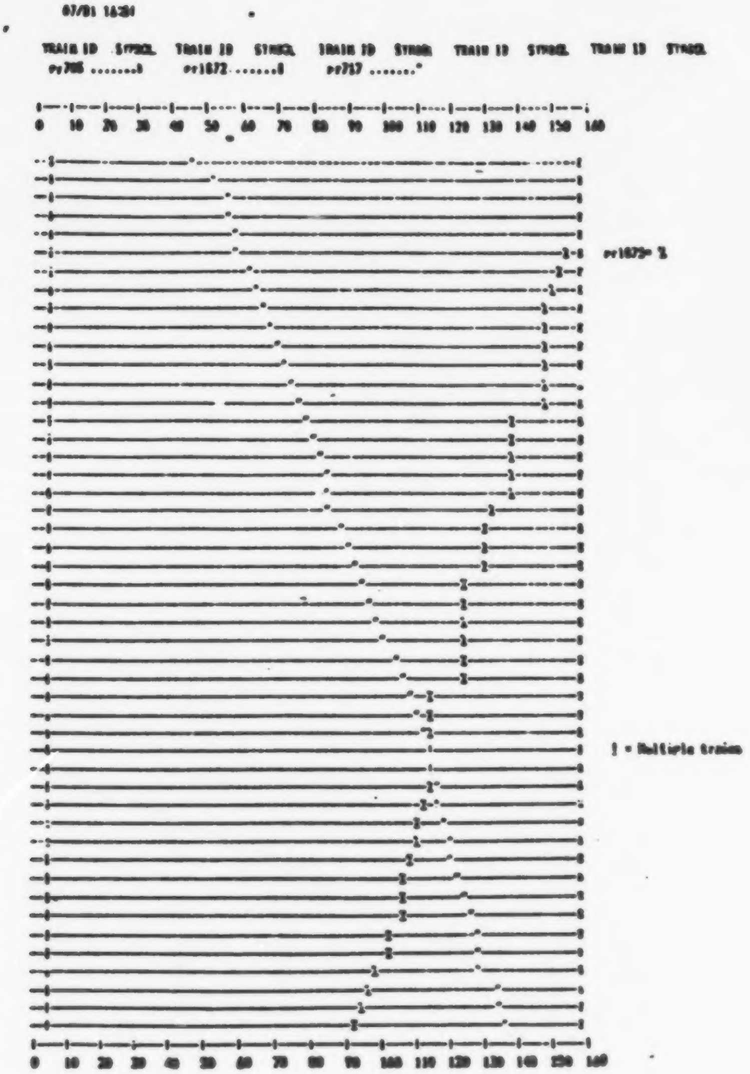
A certain amount of experimentation was required to select the optimum time interval between printed lines. An interval of five minutes was eventually decided upon. No other problems were encountered with the train location function.

7.4.3 Evaluation

The train graph gives a good representation of both current and projected train location. The graphs compare favourably with those produced in CTC systems by means of conventional pen recorder. The advantage of the LIC graph is that it shows both train identification and continuity of the tracking record and thereby eliminates a potential source of confusion.

No modifications to the train location function were found necessary.

fig. 10



BASIC TRACKING DCP TRAIN GRAPH

8. DIGITRAC MODIFICATIONS TO MEET SPECIFICATION

The basic tracking tests carried out at BC Railway showed that the mean transponder reporting success rate was only 96%. This was a lower figure than reported during the trial system tests and was certainly well short of the 99.8% capture rate called for in the specification.

To achieve the significant improvement in capture rate required, considerable work was carried out to determine the cause of the unsatisfactory performance. As a result of this work, several hardware changes were defined and a new detection algorithm was implemented. The actual changes made are as given below:

8.1 Hardware Modifications

8.1.1 The AGC detector/amplifier was cured of an uncontrolled oscillation by selecting different component values in the phase compensation network.

8.1.2 Component values in the DPSK filter were changed. Not enough bandpass in this filter caused distortion of the DPSK signal.

8.1.3 A squelch circuit was added to keep the high gain comparator only in the ON state during the time a sufficiently strong RF signal was present. Previously, random noise produced synchronization characters that forced the microprocessor into a byte-collecting routine. When actual data came in, the processor was 'busy'.

8.1.4 A buffer was added to the crystal oscillator for the microprocessor. This allows for interchanging the processor with an emulator without killing the oscillator.

8.1.5 The system clock for the UART did not meet specifications. Required clock period is 340 to 1370 nSec. Supplied was the ALE pulse 3255 nSec. The output port T0 was programmed to take this function which provided a 651 nSec clock.

8.1.6 A binary counter chip was added to provide a Frame Time Sync. signal for triggering a testscope.

8.1.7 A decoupling capacitor proved necessary on the power supply lines to the 200 KHz Phase Locked Loop. The 'Out of Lock' signal showed up on the receiver AGC line without this decoupling.

8.2 Software Modifications

As previously mentioned, it was suspected that the detection algorithm was not retrieving data under certain conditions.

Controlled testing of the system showed that the system would not detect transponders when in perfect communications with the interrogator. However, when the transponder was in a fringe communication zone with the interrogator, detection was greatly improved. Further investigation showed that in a fringe zone, the number of frames captured was very small and thus, the chance of error correspondingly small. In contrast, in perfect communications up to 256 data frames would be captured with a much higher probability of error.

It was decided to re-design the algorithm to collect a smaller number of data frames and to validate them in a very secure manner. The resulting algorithm functions in the following way:

Consider a typical data frame:

COMMA	DATA	DATA	BCC

The comma character synchronizes the serial data stream with the reader clock and initializes the sampling process. The reader attempts to capture at least three and not more than seven of these frames, providing sychronization is maintained. If less than three frames are captured, the sample is rejected and the process restarted. Each time a frame is captured, the reader increments its frame counter. When the required number of frames have been captured, the reader truncates the data to the nearest odd number of frames, i.e. three, five or seven frames. The data frames are then voted on at bit level to statistically average the data. The thresholds for voting are as follows:

Data sum $S = \sum 1's$ If $S > Tn$ bit is a one
$S \leq Tn$ bit is zero

Threshold Tn is set according to the number of frames as:

Tn	1	2	3
No frames	3	5	7

The algorithm thus votes on the data with 2 from 3, 3 from 5 and 4 from 7 voting for 3, 5 and 7 frames of data respectively. The resulting data frame is also checked for data modulus, binary check code and correct synchronization character.

The statistical nature of the new algorithm would provide a much more reliable means of detecting the four digit transponder code with the required security.

8.3 System and Lab Tests

The modifications to the system as outlined were implemented in each of the pre-production ELU Digitrac boards. The system was then tested to verify the modifications, three tests were run as outlined in the following sub-sections.

8.3.1 Test 1

Of particular interest was the dynamic behaviour of the 200 KHz Phase Locked Loop. The interrogator experiences a worst case frequency shift in the 200 KHz oscillator from +5 to -5%. A train plus interrogator at 180 Km/hr (= 1 meter per 20 mSec) spends 20 mSec over each transponder. The test was to determine if the phase locked loop could follow a frequency shift from 190 to 210 KHz in 10 mSec.

A trigger generator starts the Time Base of the oscilloscope and the swept oscillator starts increasing its frequency from 190 KHz up until, at the end of the sweep the frequency is 210 KHz. By using the Delay Time Multiplier, it is possible to select a certain portion of the frequency band and magnify that. By Triggering After Delay on the reference waveform (190-210 KHz), one can observe the jitter on the synthesized waveform (4 x f in).

The frequency-sweep time is slowly decreased to 10 mSec. A phase jitter of not more than 100 nSec was present around 190 KHz, not more than 50 nSec around 210 KHz, which is acceptable.

8.3.2 Test 2

A test was run under ideal conditions to see how many error bytes were presented to the microprocessor in a certain time. Transponder number 114 was placed over the interrogator at a distance of 20 inches. This transponder transmitted continuously the four bytes:

7C	Comma, used for synchronization
92	BCH check bits
A1	)
14	)

The 7D02 Logic Analyzer was hooked up to the Data Read Port P10-P17 of the processor. A program was set up to check the presence of the four consecutive bytes continuously. If an error occurred, the program was to halt; this was verified to work by moving the transponder away from the interrogator. The time for one pass through the loop is set by the number of bits and the speed of the Data Clock. At a Clcok frequency of 25 KHz and 4 bytes of 8 bits, a loop takes 4 microsecond x 32 = 1.28 mSec or approximately 780 loops per second. The test was stopped after 33 min or approximately 1.5 million readings; no error had caused the program to halt.

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7C	Comma, used for synchronization
92	BCH check bits
A1	} - Transponder number
14	

The 7D02 Logic Analyzer was hooked up to the Data Read Port P10-P17 of the processor. A program was set up to check the presence of the four consecutive bytes continuously. If an error occurred, the program was to halt; this was verified to work by moving the transponder away from the interrogator. The time for one pass through the loop is set by the number of bits and the speed of the Data Clock. At a Clcok frequency of 25 KHz and 4 bytes of 8 bits, a loop takes 4 microsecond x 32 = 1.28 mSec or approximately 780 loops per second. The test was stopped after 33 min or approximately 1.5 million readings; no error had caused the program to halt.

8.3.3 Test 3

Two transponders were modified to the extent that their 27 MHz transmitters could be keyed ON by a square wave. An oscillator was built that provided alternate ON pulses for the two transponders. ON times could be continuously varied with a pot, effectively acting as a train speed control. A second pot controlled the OFF time between transponder A and B. It was verified that the transmitters were at full power within 1 mSec. Both transponders were placed over the interrogator and the oscillator started. The squelch circuit in the Reader was adjusted so that two data bursts appeared at TP501, one for each transponder. It was possible with the software version TRR20 installed to have an ON time of 10 mSec and still get valid data. The actual test was run with an ON time of 20.5 mSec, allowing .5 mSEc for oscillator start up and AGC response.

A speed of 180 Km/hr is equivalent to 20 mSec/meter. If the workable operating path length is one meter, then an on-time of 20 mSec corresponds to 180 km/hr. However, the workable operating path length is determined by distance between transponder/interrogator and the setting of the squelch control. The Logic Analyzer 7D02 was hooked up to the Data Bus of the processor/UART, so that only processed transponder numbers were considered. There was no reason to believe that data errors were introduced by the UART.

The analyzer was programmed to look for four consecutive data bytes (two per transponder), and increment a counter when all bytes were correct and present. The process would then repeat. If a byte was missing or incorrect, a second counter was incremented and the process would start from byte 1. The test setup was verified and ran for 35 min.

Zero errors appeared in counter 2 and 3831 passes were recorded in counter 1. In each pass, transponder A and B were read. A second test was run overnight after increasing the transponder/interrogator spacing to 20 inches. Total run time was 12 hour 55 min = 775 min.

Counter number 1 had overflowed twice.
Number of passes: $\dfrac{775 \text{ min.}}{468 \text{ mSec}}$

This is approx. 200,000 transponder readings. The error counter showed two readings.

1. Since the first byte is used for synchronization, any errors occurring, there will not be counted. The probability of an error in the sync. byte is just as big as an error in any of the other three bytes. Therefore, the error is more likely to be four times the byte error rate of $1/3 \times 2.10^{-5}$ or $8/3 .10^{-5}$ byte per bytes.

2. Also, error bytes during 'out of sync' will not be counted. 'Out of sync' occurs during start up and after an error in the sync. byte; only the last case will be considered.

   There appear to be no systematic error sources, therefore only external influences will cause byte errors. Only if the external influence starts during the sync. byte time slot, the error will not be flagged. This is only for 1/4 of the time. The error chance for three bytes:

   $1/4 \quad 3 \times 2/3 .10^{-5}$ byte per bytes

   Total errors for (1) and (2):

   $8/3 \times 10^{-5} + 1/2 \times 10^{-5} = 19/6 \times 10^{-5}$

   This translates to three errors per 100,000 bytes, or six errors per 100,000 transponder readings.

8.4 Field Tests

The tests carried out in the lab indicated that the design changes had brought about a considerable improvement in transponder reporting. In fact, the improvement looked to have raised the reporting criteria to above the 99.8% level required for an operational system.

However, it was decided that the modifications could only be considered successful if the 99.8% level of reporting could be achieved in the field. To this end, ELU's with the modified Digitrac processor were installed in BC Railway locomotives 706, 710 and 717 and cabooses 1871 and 1872. It should be noted that one unit was heldback as a spare for on-going development.

The field trials with these units were carried out between 11 January and 29 January, 1982. The data collected is given in Appendix J. It should be noted that caboose 1871 was lost from the Squamish subdivision for most of this period and did not log any operational LIC hours. During the period given, a total of 1262 transponders were crossed, only one crossing failed to report. This correlates to a success rate of 99.92%, although with only one miss logged, the absolute credability of this figure must be questioned. However, it may be concluded that in the light of both field and lab testing, the success rate is now well above 99%. While the test were not extensive enough to statistically verify the rate is better than 99.8%, it was felt that the system was now sufficiently reliable for an operational implementation.

The scheduled test for full-tracking on the operational system would provide the opportunity to fully prove the remarks made above.

9. CONCLUSIONS

The pre-production prototype project for the development of LIC system train-borne equipment has been successfully completed. Each of the items in the statement of work has been addressed and this final report represents the conclusion to the project.

Much has been achieved during the project. The LIC system and equipment are now at a stage in devlopment where an operational installation is practical and desirable. The change in system operation from dynamic to fixed block control brought about a complete re-design of the on-train hardware. Pre-production equipment was built and functionally tested, the final phase of testing included a one month field trial. Following several revisions, the equipment met the requirements defined for the operational system. The resulting designs are now at a stage where construction of production equipment can be contemplated.

The remainder of this part will discuss the state of the present development and the conclusion drawn from the work carried out.

9.1 Engine Logic Unit (ELU)

At the conclusion of the trial system development, disappointment was expressed in the suitability of the RCA 1802 microprocessor as the train borne CPU.

The new design uses a second generation microprocessor that is much more suited to real-time control system applications. The microprocessor used is the Zilog Z80A which has achieved extensive usage throughout the industry. The previous processor was typified by a lack of support and development software, a limited instruction set and slow processing speed. The adoption of the Z80 has overcome all of these limitations and the new design has shown itself to be far superior.

With the move to the Z80 microprocessor, a rewrite of the applications program was necessary to reflect the change in assembly level programming. A well proven method of structured programming was adopted to ensure that the resulting software was reliable and easily maintained. The extensive range of debugging tools and program generation facilities available for the Z80 proved to be invaluable during software development.

The mechanical layout of the ELU has been greatly improved, in particular, the troublesome edge connectors of the previous rack-mounted design are no longer used. The inclusion of a power supply to derive all on-board DC levels means that the ELU only requires a single 12 VDC input. This feature ensures interchangeability of ELU's between engine and caboose applications.

The ELU has been tested during a series of system and field tests. It was concluded that in each of the key functional areas of transponder reporting, odometer calibration and communications, the Unit met the specification. Particular consideration was given to ensuring that the new design gave comparable or improved performance over the old design.

It was concluded that the new ELU was a significant improvement over the old design and through better performance, reliability and flexibility is better suited to an operational installation.

9.2 Cab Display Unit (CDU)

As a result of the trial system development, it was concluded that the cab display required improvements in the image readability and security areas.

The cab display designed in this project achieved a level of performance not available with the previous design. The unit has been modularized and now contains all of its drive electronics on-board. The inclusion of a dedicated Intel 8748 microprocessor in this electronics has significantly improved the ELU-CDU interface techniques. Additionally, the display drive electronics in the new unit is superior in that it maintains a steady flicker-free readout during display refresh.

Procedures for passing messages from the ELU to CDU have been developed which will ensure the fail-safety of displayed instructions. The methods used rely on a full readback of the data, followed by a comparison with the message sent before the data is actually displayed.

The display now functions to show fixed block authorities, route and direction, each of which is displayed in spelled out form and abbreviated form. This affords a level of cognitive diversity which will further enhance fail-safety.

The cab-display was subjected to a rigourous environmental test procedure for temperature, humidity and vibration. The design showed its capability to continue operation under the most severe extremes of these tests. The virbration tests resulted in several minor changes to the packaging to remove resonant fixings.

In the course of testing the CDU, the display proved to be highly readable under a wide range of ambient lighting conditions. However, some washout was still present under conditions of direct sunlight. It is our opinion that this problem cannot be solved until new display technologies become available.

The cab display unit and associated control software was not adequately tested by the in-house testing and a period of field testing must be planned for the future. In its present form, the cab-display is suitable for operational implementation, providing the display panel can be protected from direct sunlight.

9.3 Digitrac Reader

The Digitrac reader now utilizes a dedicated Intel 8748 microprocessor to perform transponder data-recovery tasks. The use of this particular microprocessor was chosen in view of the hardware commonality afforded with the cab-display unit.

A further benefit was the inclusion of a 12 V to 72 V DC converter on the board to provide the required interrogator power supply. This was in keeping with the power supply concept of the ELU previously mentioned.

The reader in its new configuration is totally modular and may be used in other applications requiring a transponder detection capability.

The field tests at first proved to be disappointing as the transponder capture rate was only 96%, which was a drop since trial system testing. A full investigation uncovered several inherent design problems in the receiver circuit and detection software. On correction of these problems, a limited test of over 1200 transponder crossings was carried out, the capture rate was in excess of 99.9%.

It was concluded that the transponder reader used in the trial system contained design errors which were carried over to the new design. These errors have now been corrected and it is expected that further testing will conclusively prove that the capture rate exceeds the 99.8% level required for the operational system.

9.4 System

Insofar as the system is concerned, the ELU, CDU and peripherals have demonstrated their suitability for railroad applications. The new functions of the system associated with fixed block control of trains have not been fully proven at this stage of development. However, results from initial tests seem to indicate that there is a greater potential for safety with the fixed block system than with the dynamic block.

While not covered by this project, it is timely to mention the LIC prototype Data Collection Processor (DCP), which acts as a front-end to the central computer. The DCP handles all communications with the ELU's and assists the central computer in making vital decisions. It was found during the testing carried out in the project that the DCP's performance was less than adequate. The design used is a purpose built Z80 based system produced in-house by Glenayre. While the problems could have been solved, the time to do so was considered excessive. In the light of this decision, it was decided to review the detailed design of DCP, with a view to producing a more effective and expandable design. The implementation of such a design at this stage would lead to a DCP more easily adapted to more advanced forms of the LIC system, such as that required for mainline railroads.

10. RECOMMENDATIONS

On the basis of the work carried out and conclusions reached during this project; it is recommended that the LIC project proceed with an operational inistallation on the Squamish Sub-division of BC Railway. Furthermore, the following recommendations are made:

a) Further transponder detection data should be collected, with a sample size of at least 10,000 crossings. This will allow the accurate determination of the capture rate and will conclusively prove that performance exceeds the specified 99.8% level.

b) The odometer calibration, wheel wear factor function should be implemented and tested prior to the operation of the final system. In addition, the sub-division chaining should be accurately checked to ensure all errors have been corrected.

c) Consideration should be given to the effect that known communications fade zones will have on the system when control functions are implemented.

d) The design of Glenayres status indicator should be completed. This together with the implementation of ELU software changes will allow for field monitoring of system performance. The unit will also be valuable as a fault diagnosis tool during test of the operational ELU's.

e) The fixed-block control software and cab display control software should be evaluated in the field at the earliest possible date. Particular attention should be paid to ensuring that the system is fail-safe and can maintain train safety.

f) The detailed design changes and any other changes defined for the operational system should be documented in the final production drawings. The new ELU and CDU designs can then be released to production for manufacture of the required units for installation on BC Railway.

g) Whilst outside the scope of this project, the following recommendation is made for future development of the DCP. It is recommended that a new DCP be designed around a proprietary databus and compatible boards available from several manufacturers. The central processor board should be a Z80A running at 4 MHz, and should be programmed in Pascal. The cards should be housed in a standard rack which should also incorporate the necessary power supplies.

The move to such a DCP will greatly enhance system performance and will provide the necessary expansion capability for more ambitious implementations of LIC.

LIST OF REFERENCES

1. LIC System DCP/ELU communications Protocol and Message Catalogue. Glenayre document GL2025-005, Issue 5, August, 1981.

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3. Vehicle Logic Unit (VLU) Hardware Specification. Glenayre document GL6580-001, Issue 1, February 1980.

4. Location Identification and Control (LIC) System - Train Subsystem Specification. Glenayre document GL2025-002, Issue 4, June 1980.

5. LIC System Design Specification. Glenayre document GL2025-006, Issue 1, February 1980.

6. Location Identification and Control System Environmental Specification, Glenayre document GL2025-007, Issue 1, June 1980.

7. LIC System Engine Logic Unit (ELU) Software Specification. Glenayre document GL2393-004, Issue 2, October 1980.

8. Location Identification and Control System Data Collection Processor Software Specification. Glenayre document GL3488-001, Issue 4.2, December 1981.

9. Location Identification and Control Project Remote Site Unit - Technical Description. Glenayre document GL6610-001, Issue 3, March, 1981.

10. Final Report: Radio-Linked Train Location Identification and Control Phase II - March 1979. By Dr. R.J. Pomeroy, Glenayre Electronics Ltd.

11. Glenayre DIGITRAC System - Technical Manual. Glenayre document GL6000-001, Issue 3, March 1981.

12. Glenayre Standard Practice Instruction. Glenayre document GL-8000-002, Issue 1, June 1978.

APPENDICES

APPENDIX A

OVERVIEW OF THE OPERATIONAL LIC SYSTEM

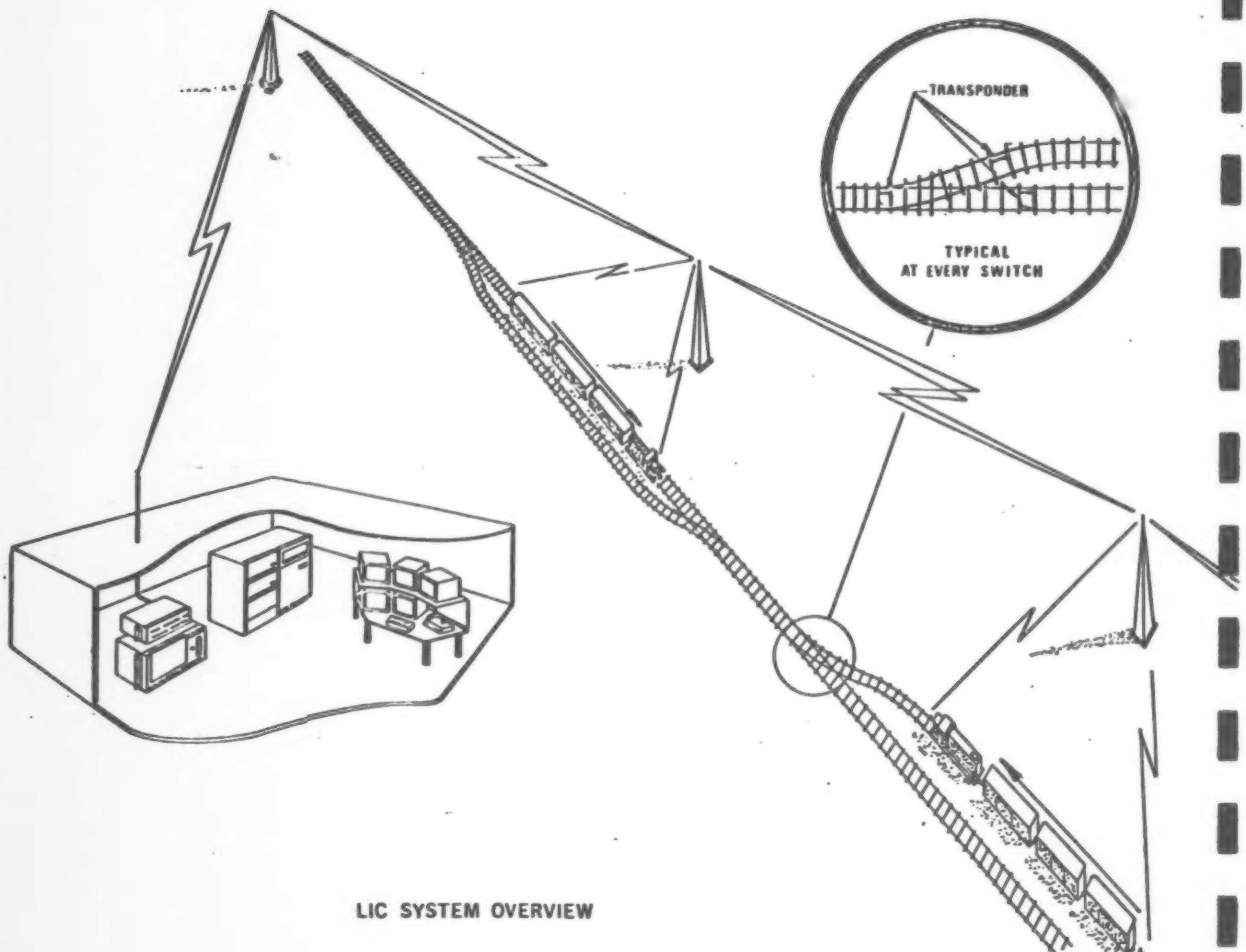
Overview of the Operational LIC System

A diagram of the LIC System is shown in Figure 1. It shows digital radio communication between the central dispatch facility and both ends of the trains operating on the main track of the railroad. Trains transmit their vital information, including identification, location, speed, and additional supplementary status information. The central dispatch facility transmits operating instructions to each train.

The communications link between central and each train is a vital element of the system. High security is achieved in the block-organized polling-response system by the use of cyclic redundancy codes, and by the adoption of an enable-check-execute sequence on all vital transactions. The redundancy code (BCH is the one used) uses less than 25 percent of the message capacity, but provides the required security at the signal-noise ratios encountered. BCH has the capability for forward error correction but it has not been found necessary to utilize this capability. For all movement authorities and all reports of entry into and exit from a control block, a confirmation message is required from receiver to sender before the sender can conclude that his message has been received correctly. The added security provided by this confirmation sequence virtually eliminates the possibility of an error entering either the central or train computers through an error in the communications link.

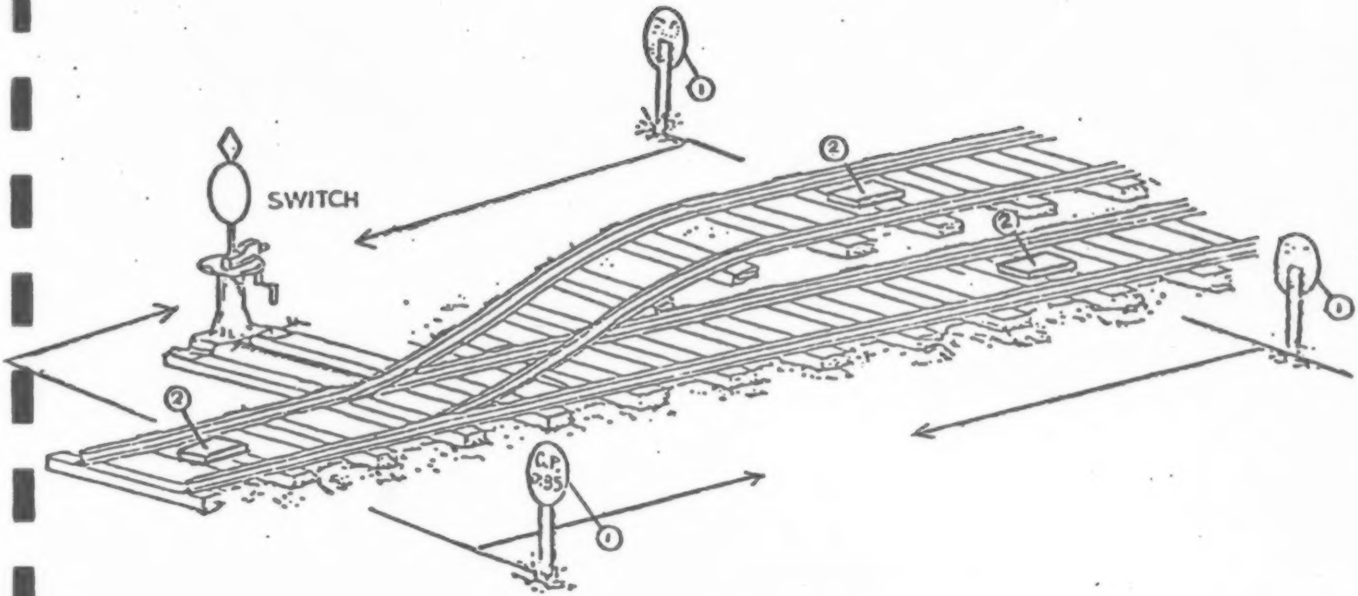
For reliability, the entire communications link (radios, remote site unit and microwave channel) are duplicated. The computer selects the links alternately on each successive polling cycle to ensure that both links are operating. Should one link fail, the alternating procedure is suspended and a warning message is generated. When the system is informed that the failed link is restored then the alternating scheme is resumed.

Transponders, each with a unique, identifying code, are mounted on the roadbed between the rails. A typical installation around a switch is shown on the inset of Figure 1, with the transponders located 50 feet from the switch or at the fouling point of adjacent track. Other locations for transponders include main track when the distance between sidings is great, and at entry/exit points from the main track. Transponders are used to establish control points and the intervening blocks. The geometry of control points at a switch and on main track are shown on Figures 2 and 3 respectively. The control points are basic steps of movement authority and no train may cross a control point without authority in the form of either cab display or written instruction. Other forms of authority comprise switching, which applies to one control point only, and restricted proceed, which allows train movement not to exceed restricted speed in permissive block operation.


TRANSPONDER
TYPICAL
AT EVERY SWITCH

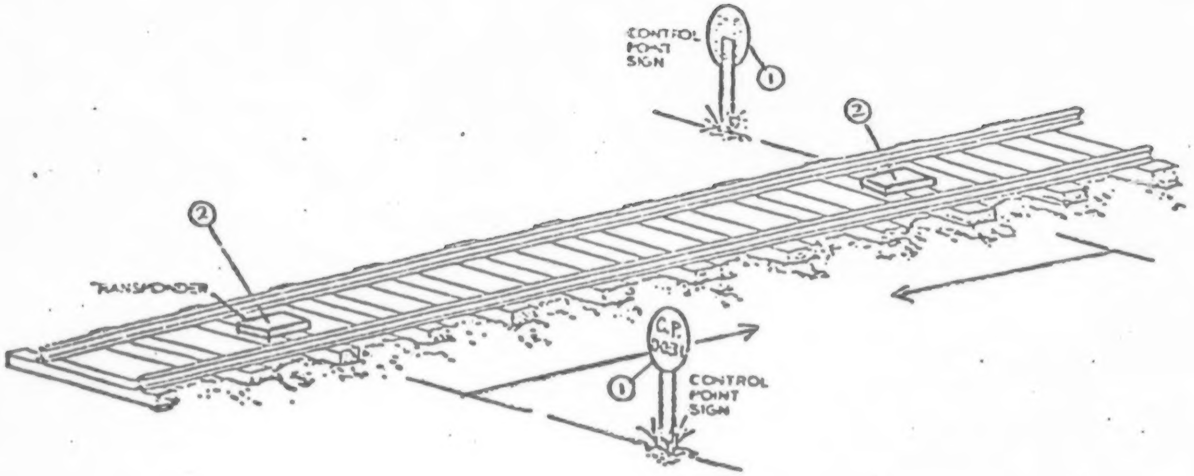
LIC SYSTEM OVERVIEW

FIGURE 1


SWITCH
①
②
C.P.
7.95

CONTROL POINT AT A SWITCH

FIGURE 2


CONTROL POINT SIGN
①
②
②
TRANSPONDER
C.P.
①
CONTROL POINT SIGN

CONTROL POINT ON MAIN TRACK

FIGURE 3

Each unique transponder number, when picked up by the Interrogator on board a locomotive or caboose and reported to the central computer, serves as a location fix. The fix is used to:

- calibrate the locomotive odometer derived from an axle generator
- confirm passage of the locomotive over a control point into the next block
- confirm passage of the caboose over a control point and clear of a block
- confirm the route taken through a switch

The train equipment includes an Engine Logic Unit (ELU) and Cab Display Unit (CDU) in the lead locomotive. These provide the engineman with a plain language alphanumeric display of important operating data comprising:

- speed
- location
- control point instructions
- directives

This information is continually updated and monitored, partly by processing done on board the locomotive and partly through message exchanges with central.

The speed indication and the odometer are computed from the output of an axle generator on the locomotive. They are updated every half second and displayed digitally. The speed indication is displayed continuously but the odometer must be initialized and calibrated by messages from central. The precise location of the next transponder is transmitted to the locomotive ELU and when that transponder is crossed, the odometer is initialized. The accuracy of the odometer is continuously monitored and is maintained correct within the precision (0.1 mile) of the display indication. Re-calibration occurs automatically and is transparent to the train crew.

Control Point Instructions give authority to the train crew to carry out their duties. For main track movements, instructions appear on the display in the format shown in Figure 4. The current instruction appears between horizontal dashed lines, with the next instruction below it, and the next after that on the bottom line of the display. Three (3) more instructions may be stored in the computer. An instruction is considered executed when both of the transponders at a Control Point are read in the correct sequence. At this time the display rolls up, the current instruction is replaced by the one below and instruction moves up one line, and a stored instruction from the computer appears on the bottom line. If no more instructions have been issued then a blank line will appear at the bottom of the display. This gives advanced notice to the engineman that the train must be stopped ahead, and states the last control point which can be crossed. When all authorities are executed then a directive to stop before the next control point is displayed for the engineman.

Authority for switching moves and for proceeding at restricted speed are also issued using prescribed formats on the cab display. Less frequently required activities and movements can be handled by written orders.

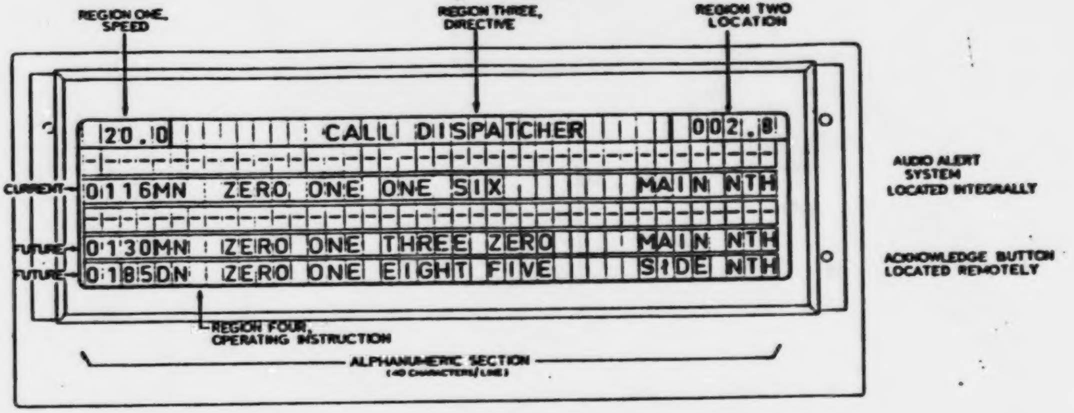
Central Dispatch Office Equipment

The Central Dispatch Office equipment consists of a PDP 11/44 Host computer, a Data Collection Processor (DCP), three (3) colour video display units, plus video terminals and printers required for dispatcher interaction. Figure 5. shows a block diagram of the equipment.

The DCP is linked to the communications network, and handles transactions with the locomotives and cabooses, collects and maintains a data base, maintains odometer calibration, passes messages from the Host to the locomotive equipment for display, and maintains vigilence for speak-up messages which are sent by any locomotive which illegally crosses a transponder.

The DCP is a microcomputer unit which serves to relieve the Host of the task of polling and data collection. It also has the capability to operate in a "stand-alone" configuration without the Host. In this configuration it tracks trains and produces a train graph, but has only limited interactive capability with the dispatcher.

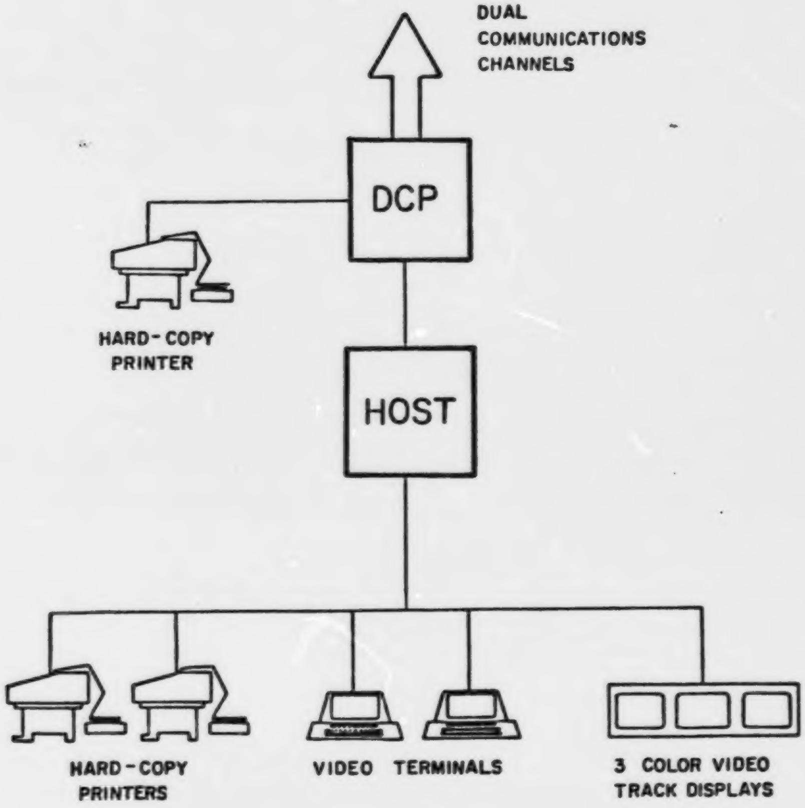
The Host computer, as shown in Figure 5., requests data from the DCP when required and maintains it's own data base. It has interactive devices, displays, and report printers connected to it. The major input/output capabilities of the Host include display of the track diagram and track positions on three-colour video display units.


REGION ONE, SPEED
REGION THREE, DIRECTIVE
REGION TWO LOCATION
20.0
CALL DISPATCHER
002.8
CURRENT
0116MN ZERO ONE ONE SIX MAIN NTH
FUTURE
0130MN ZERO ONE THREE ZERO MAIN NTH
FUTURE
0185DN ZERO ONE EIGHT FIVE SIDE NTH
AUDIO ALERT SYSTEM LOCATED INTEGRALLY
ACKNOWLEDGE BUTTON LOCATED REMOTELY
REGION FOUR, OPERATING INSTRUCTION
ALPHANUMERIC SECTION
(40 CHARACTERS/LINE)

LOCOMOTIVE CAB DISPLAY FORMAT

FIGURE 4

THE FIRST OPERATIONAL IMPLEMENTATION OF THE LIC SYSTEM


DUAL
COMMUNICATIONS
CHANNELS
DCP
HARD-COPY
PRINTER
HOST
HARD-COPY
PRINTERS
VIDEO TERMINALS
3 COLOR VIDEO
TRACK DISPLAYS

CENTRAL DISPATCH OFFICE

EQUIPMENT BLOCK DIAGRAM

FIGURE 5

Three display units, mounted side-by-side, show the entire Squamish Sub-Division. Colour conventions show usage such as unoccupied track, occupied track and maintenance of way. The trains are shown to a precision of a 1/4 mile using an arrowhead and train identifier. Track and train status changes are shown both by colour change and by the use of blinking.

The interactive alphanumeric video terminals are used for entry of data by the dispatcher and for the display of working information. The Host computer maintains a computerized train sheet on all trains. Supply data for the train sheet is entered by the dispatcher when the train is called. The complete record of a trip is maintained in the computer and is stored on magnetic tape when the trip is complete.

The Host computer tracks each train and shows it's updated location on the track diagram. It also handles the traffic management logic whereby trains are given movement authority without creating conflict. It is the dispatcher's responsibility to maintain safety in the instructions which he issues, but the computer completely checks every instruction and maintains records of which sections of track are occupied and which are free. Control Point instructions given to a train prevent any other user from obtaining authority for those blocks of track until each is released to other users when the caboose crosses both transponders of the control point.

Many techniques are used within the central dispatch hardware to ensure system integrity. These include software diversity, enable-check-execute sequences for vital actions, mutual data base checking by the DCP and Host, range, reasonableness and sequence tests on all data, and hardware performance monitoring.

To provide maximum availability of the system, hot standby equipment is incorporated into the dispatch office hardware configuration. The online and standby equipment are inter-connected through a fault indicator panel. The Panel permits manual selection of which equipment is on line, and monitors each DCP and Host computer for status and failure indications. Should a failure occur, the system automatically switches over to the standby equipment.

APPENDIX B

DETAILED STATEMENT OF WORK

WORK STATEMENT

LICS PROTOTYPE EQUIPMENT

18 JULY 1978

1. INTRODUCTION

In response to an unsolicted proposal submitted by Glenayre Electronics to the Department of Supply and Services (DSS) in December 1974, the Transport Canada Research and Development Centre (TDC) indertook a project to further the development of a Location, Identification and Control System (LICS) of railway signalling. The initial project carried out under DSS contract OST5-00005 successfully met all its objectives and resulted in the design, fabrication, and testing of experimental LICS hardware. (Refer to final report 'Radio-Linked Train Location, Identification and Control', Glenayre Electronics, November 1977 - Transport Canada TP 1216). A subsequent project carried out under DSS contrtact OST77-00005 has led to the implementation and evaluation of a trial LIC system on BC Rail. This work is expected to be completed in late 1978. Contracts for related work have been awarded to BC Rail to develop the central dispatch facilities, and to Canadian Pacific Consulting Services to evaluate the operational effectivenss of LICS. The Transport Canada T & E Branch Quality Assurance Division has carried out a reliability analysis of the system.

The next major step in LICS development is expected to be the introduction into operational service of a full scale LIC signalling system, but the time frame for such an implementation is uncertain. Despite the extensive testing which has been carried out to-date, the design of the LICS electronic equipment has remained essentially unchanged since early 1976. A number of problem areas have been identified but these have not yet been corrected. This project will review the design of the LICS equipment in light of the extensive field experience to-date and construct three sets of pre-production prototype hardware. The equipment will be subjected to rigorous testing in anticipation of future operational demonstration of LICS.

2. OBJECTIVES

The objectives of this project are:

2.1 Review the design of the LICS electronic equipment in light of the performance analysis which has been carried out, and the field experience with the trial LIC system on BC Rail.

2.2 Produce an updated design for the locomotive mounted electronic logic unit (ELU) and the cab display (CDU).

2.3 Construct and test three sets of pre-production prototype locomotive electronic equipment.

3. STATEMENT OF WORK

The work to be carried out by Glenayre Electronics under this contract shall consist of:

3.1 Review the design of the electronic logic unit (ELU) and incorporate design changes as may be necessary to take advantage of the latest advances in microprocessor technology to simplify the program generation. Efforts shall be made to enhance the reliability of the unit and increase security through the use of distributed logic and redundant processors. Incorporate built in test equipment (BITE) features to the greatest extent practical to improve the maintainability of the unit.

3.2 Review the design of the cab display unit (CDU) and incorporate design changes as may be necessary to improve the readability of the display under all conditions of ambient light. Careful attention shall be given to the packaging of this unit to ensure good vibration resistance. The electronic design shall be brought into line with the distributed logic concept of the ELU.

3.3 Review the design of the transmitter unit and the transponder and incorporate any design changes which may be necessary to ensure compatibility with the modified design of the ELU.

3.4 Prepare environmental specifications for the LIC locomotive electronic equipment. The design reviews of 3.1, 3.2 and 3.3 and resulting design changes shall incorporate considerations for the conditions defined in the environmental specifications.

3.5 In carrying out the design changes, the comments contained in the draft report 'Location, Identification and Control System - Reliability Analysis and Failure Mode and Effect Analysis', Transport Canada Quality Assurance Division shall be given special attention. In addition, Glenayre shall consult with personnel of the Quality Assurance Division regarding the proposed design changes before finalization of the ELU and CDU designs.

3.6 Construct three sets of pre-production prototype locomotive electronic equipment, each set consisting of one ELU and one CDU.

3.7 Prepare environmental test plans and procedures for approval by the TDC Project Officer and carry out environmental tests, in accordance with the approved plans and procedures, of one set of the equipment of 3.6 above under controlled conditions of temperature humidity and vibration.

3.8 Modify the design of the equipment as may be required following the completion of environmental tests. Prepare and submit to TDC in reproducible form one complete set of the final production drawing and data for the ELU and CDU.

3.9 Prepare and deliver to TDC 50 copies of a final report describing the work which was carried out and the results achieved.

NOTE: The statment of work was expanded to include the following additonal work items:

3.10 Re-design the ELU power supply to operate from 12 VDC in order to handle both the locomotive and the caboose installation.

3.11 Review and re-design as necessary to comply with the ELU reliability, maintainability and fail-safe requirements.

3.12 Perform the necessary field testing of the re-designed ELU.

APPENDIX C

LOCATION, IDENTIFICATION AND CONTROL SYSTEM

BASIC TRACKING TEST PLAN

SCOPE

1. This document defines the basic tracking tests which must be performed with the dlievery of the six pre-production engine logic units and one DCP.

2. Two basic standards must be met, environmental standards and operating standards, as defined in applicable environmental tests will be conducted by Glenayre Electronics and operating tests by BC Railway.

TEST REQUIREMENTS

1. Schedule 'A', Task 3 (c) and (d), of British Columbia Railway's contract requirements of the Work Statement dictates the following:

   - Development and test the software for automatic tracking of LIC equipped trains through the Squamish Subdivision.

   - The software system shall be designed to maintain records of transponders successfully received, communications performance and odometer calibration and the location of each LICS train on the subdivision.

   - Demonstrate the successful operation of the basic train tracking through operation, data collection, and evaluation of these functions during a trial period of at least one week.

   - The initial installation will comprise of six pre-production engine logic units which will be installed in three engines and three cabooses. The three engines and cabooses will be tracked by a pre-production DCP model through the completely installed communication system.

   - The one weeks successful demonstration will be fulfilled after each equipped unit has been tracked for seven consecutive trips over the Squamish Subdivision.

   - The MU valve feature on the first three engines will be disabled to allow multiple tracking within the same power consist.

2. Individual tests which must be documented are as follows:

   Transponder Tests - each unit must report transponders 99.8% accurately for seven consecutive trips over the Squamish Subdivision.

   Communications Performance Tests - for each unit, the following data must be recorded for seven consecutive trips over the Squamish Subdivision. BC Railway unit number, date, time, group of trip, total messages transmitted, and the total responses received.

Odometer Calibration Tests - each of the equipped engine units will make seven consecutive trips over the Squamish Subdivision and reports will be generated with the following data:

BC Railway unit number, data, time, group of trip, the location of each calibration and the calibration error at each calibration location.

Train Location Tests - the train image shall consist of the odometer reading of the locomotive every five minutes during the time the train is being tracked. The form of the image shall be a table of time and mileage. Cabooses will be tracked and imaged at last control point crossing.

In addition to the above mentioned tests, British Columbia Railway will conduct system loading tests with the first six units. As additional units come on stream, the system loading test will increase up to a maximum of 40 units.

TEST PLAN

1. Transponder Tests - the transponder reporting information will be made available on the DCP events printer. This information will be manually transcribed into the required format.

   British Columbia Railway are responsible to conduct the tests and provide the statistics. If the 99.8% reporting is not achieved, Glenayre is responsible to determine why. If the problem can be traced to BC Railway's communications system, then BC Railway will assume responsibility.

   If BC Railway are satisfied that the problem can be corrected during the 'Rework' phase, then the tests will be considered complete.

2. Communications Test - a separate test list of communications statistics will be compiled for each of the six units. The information required will be:

   - Total number of transmissions for that trip
   - Total number of responses received for that trip
   - Total number of speak-up messages for that trip
   - Individual site coverage statistics for that trip

   The communications statistics are printed on the DCP events printer and will be manually transcribed into the required format. Glenayre are going to provide assistance by grouping this information at pre-determined intervals. BC Railway are responsible to conduct the tests and provide the finished statistical reports. In the event of unsatisfactory performance, BC Railway will be responsible to determine why.

3. Odometer Calibration Tests - a separate list of statistics will be compiled for each of the three engines equipped. The information required will be:

   - Speak-up at first transponder detected
   - Infer direction at second transponder detected
   - Calibrate odometer at third transponder which is at least one mile from second transponder
   - The odometer will not be re-calibrated after initial calibration, but references will be recorded at transponder crossings to actual known location versus odometer reading

   This information will be recorded on the DCP events printer and will be retrieved and transcribed manually onto test form. BC Railway will be responsible for this task.

   In the event of unsatisfactory performance of the calibrate feature, Glenayre will be responsible to determine why and correct. Additional tests must then be conducted until proven.

4. Train Location Tests - this test will be provided on a dedicated printer driven by the DCP, the printer will provide a time distance graph. Each of the six units will be tracked over the subdivision. Engines will have their location stamped every five minutes, cabooses will be identified at all control point crossings.

   BC Railway are responsible to gather the graphs and monitor the operation for correct reporting. In the event the train location tests are not satisfactory, it will become Glenayre's responsiblity to determine why. Corrections must be made until statistics can be gathered as required.

5. System Loading Tests - all six units will be included in one train. The communications link will be manually interrupted in each site coverage area. After sufficient time has lapsed to put all ELU's in communication failure, the link will be restored.

   The DCP must be capable of handling the six speakups from each individual site.

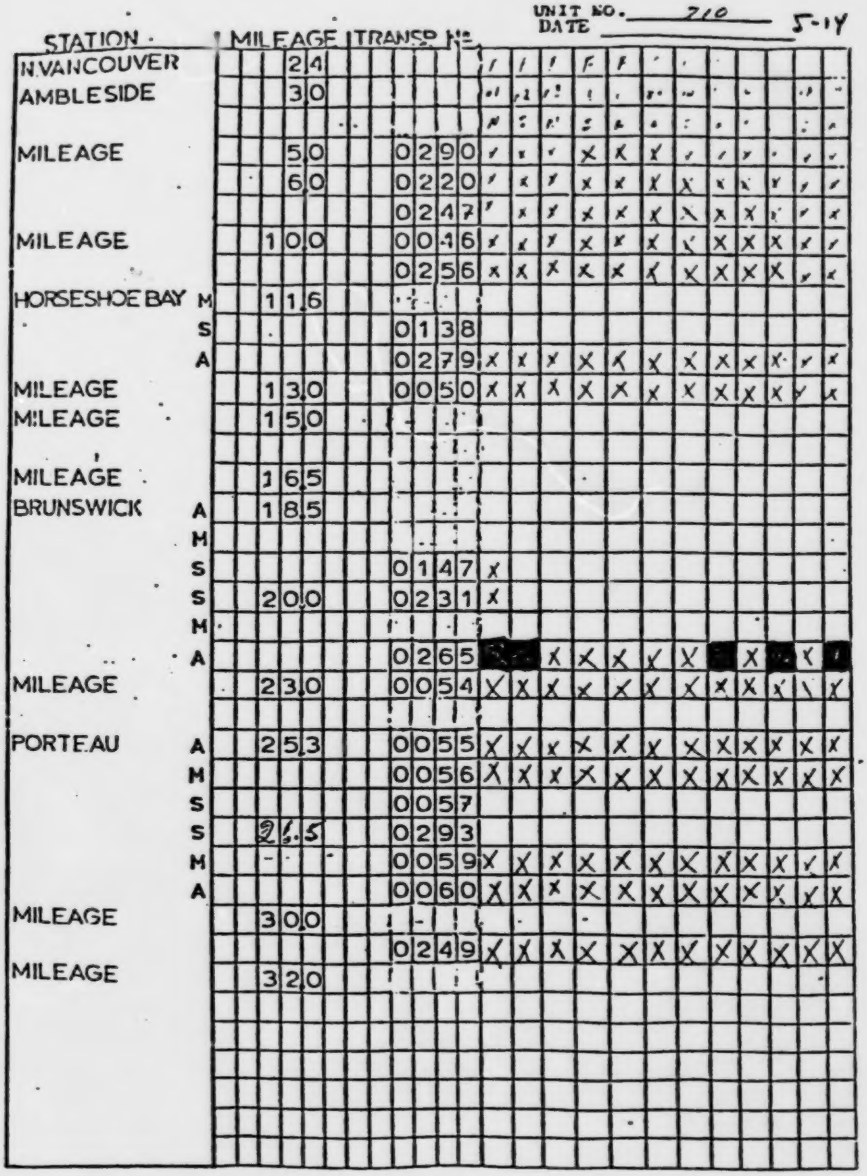
   If the test is unsatisfactory, it will be Glenayre's responsibility to determine why and correct. The test will then be re-run to confirm positive results as required.

DOCUMENTATION

British Columbia Railway will gather all above tests into a basic test document and provide conclusions and recommendations.

APPENDIX D

EXAMPLE OF TRANSPONDER DATA USED TO COMPILE TRACKING TRANSPONDER SUMMARY

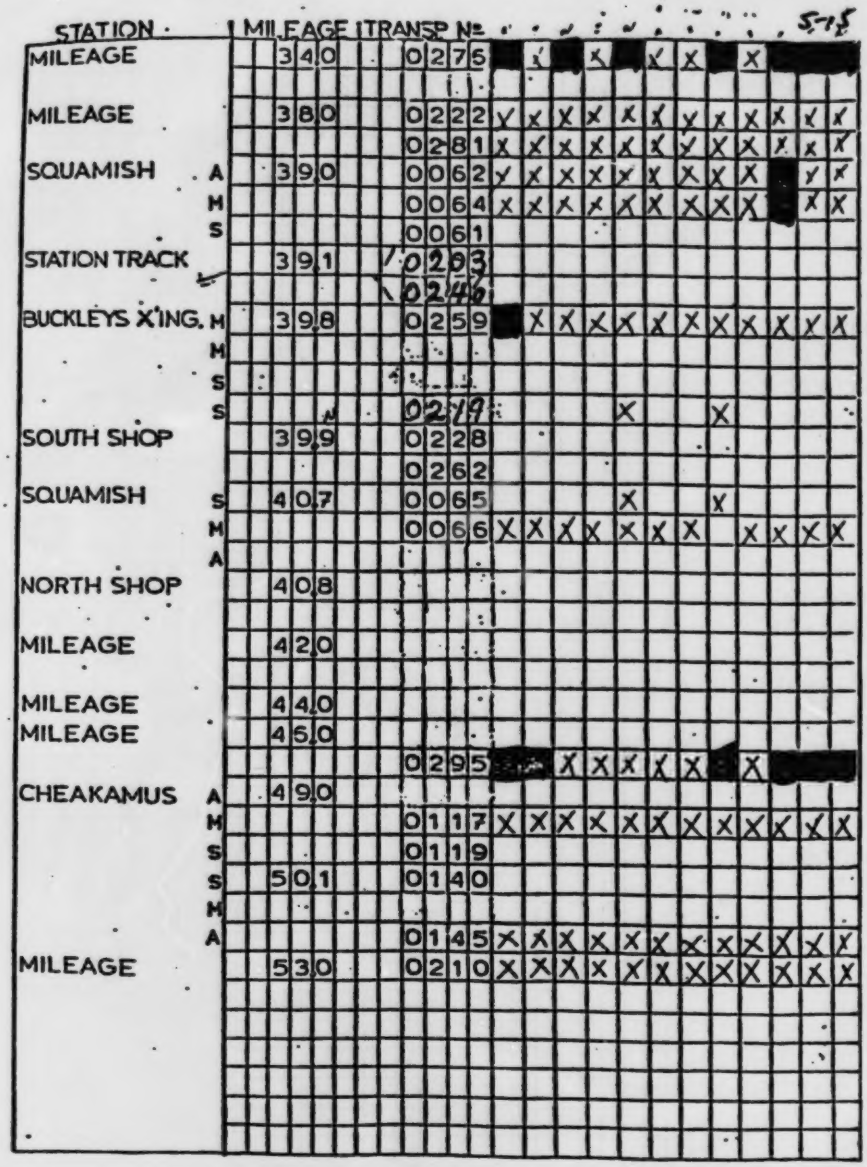


UNIT NO. 710
DATE 5-14

STATION		MILEAGE	TRANSP Nº												
N.VANCOUVER		2.4		/	/	/	/	/							
AMBLESIDE		3.0													
MILEAGE		5.0	0290	/	/	/	X	X	X	/	/	/		/	/
		6.0	0220	/	X	/	X	X	X	X	X	X	X	/	/
			0247	/	X	X	X	X	X	X	X	X	X	/	X
MILEAGE		10.0	0016	X	X	X	X	X	X	X	X	X	X	/	/
			0256	X	X	X	X	X	X	X	X	X	X	/	X
HORSESHOE BAY	M	11.6													
	S		0138												
	A		0279	X	X	X	X	X	X	X	X	X	X	/	X
MILEAGE		13.0	0050	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		15.0													
MILEAGE		16.5													
BRUNSWICK	A	18.5													
	M														
	S		0147	X											
	S	20.0	0231	X											
	M														
	A		0265	[redacted]	[redacted]	X	X	X	X	X	[redacted]	X	[redacted]	X	[redacted]
MILEAGE		23.0	0054	X	X	X	X	X	X	X	X	X	X	X	X
PORTEAU	A	25.3	0055	X	X	X	X	X	X	X	X	X	X	X	X
	M		0056	X	X	X	X	X	X	X	X	X	X	X	X
	S		0057												
	S	27.5	0293												
	M		0059	X	X	X	X	X	X	X	X	X	X	/	X
	A		0060	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		30.0													
			0249	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		32.0													

EXAMPLE OF RAW TRANSPONDER DATA USED TO COMPILE BASIC TRACKING TRANSPONDER SUMMARY

FIGURE (a)



STATION		MILEAGE	TRANSP No												5-15
MILEAGE		34.0	0275	■	X	■	X	■	X	X	■	X	■	■	■
MILEAGE		38.0	0222	X	X	X	X	X	X	X	X	X	X	X	X
			0281	X	X	X	X	X	X	X	X	X	X	X	X
SQUAMISH	A	39.0	0062	X	X	X	X	X	X	X	X	X	■	X	X
	M		0064	X	X	X	X	X	X	X	X	X	■	X	X
	S		0061												
STATION TRACK		39.1	0203												
			0246												
BUCKLEYS X'ING.	M	39.8	0259	■	X	X	X	X	X	X	X	X	X	X	X
	M														
	S														
	S		0219					X			X				
SOUTH SHOP		39.9	0228												
			0262												
SQUAMISH	S	40.7	0065					X			X				
	M		0066	X	X	X	X	X	X	X		X	X	X	X
	A														
NORTH SHOP		40.8													
MILEAGE		42.0													
MILEAGE		44.0													
MILEAGE		45.0													
			0295	■	■	X	X	X	X	X	■	X	■	■	■
CHEAKAMUS	A	49.0													
	M		0117	X	X	X	X	X	X	X	X	X	X	X	X
	S		0119												
	S	50.1	0140												
	M														
	A		0145	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		53.0	0210	X	X	X	X	X	X	X	X	X	X	X	X

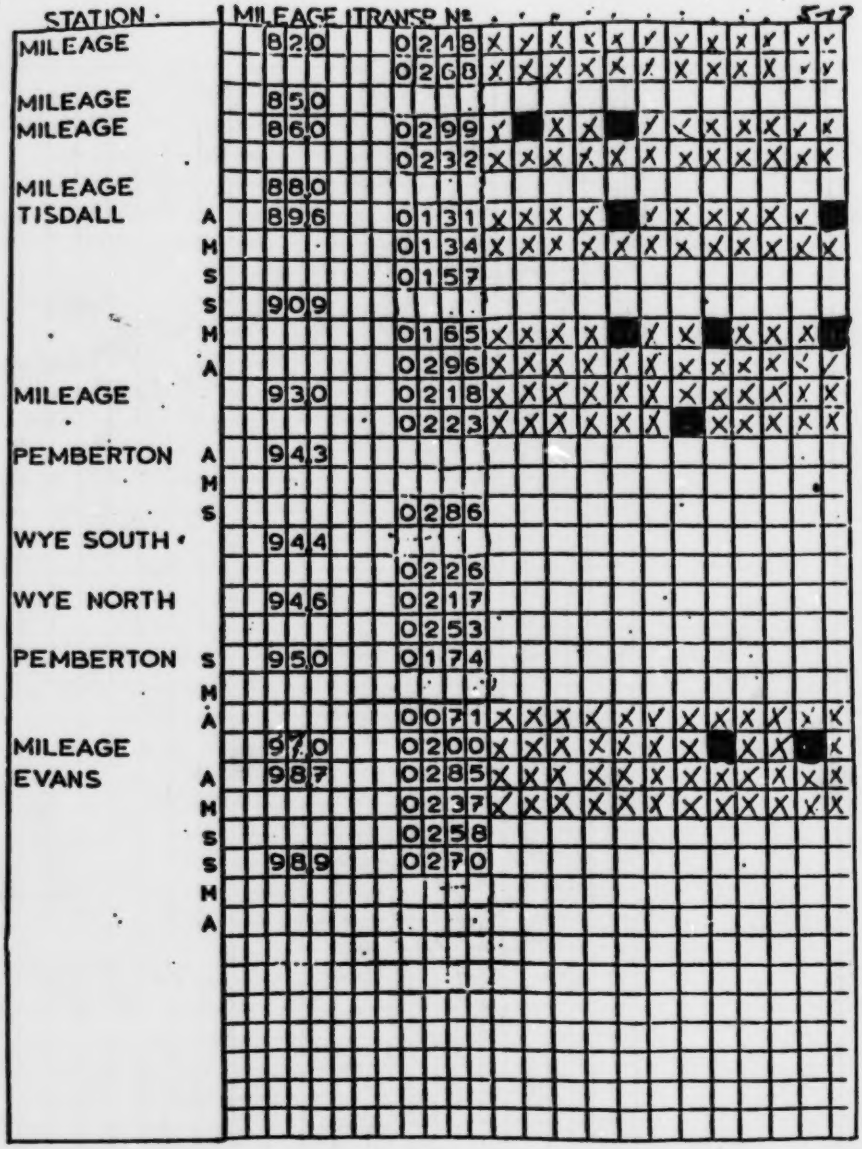
EXAMPLE OF RAW TRANSPONDER DATA USED TO COMPILE BASIC TRACKING TRANSPONDER SUMMARY

FIGURE (b)

STATION		MILEAGE	TRANSP Nº												5-78
MILEAGE		550													
MILEAGE		580													
GARIBALDI	A	589	0073	X	X	X	X	X	X	X	X	X	X	X	X
	M		0151	X	X	X	X	X	X	X	X	X		X	
	S		0152										X		X
	S	600	0153										X		X
	M														
	A		0115	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		630	0172	X	X	X	X	X	X	X	X	X	X	X	X
			0252	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		640	0298	■	X	X	X	■	X	X	■	X	■	■	■
McGUIRE	A	664	0072	X	X	X	/	X	X	X	X	X	X	X	X
	M		0171	X	X	X	X	X	X	X	X	X	X	X	X
	S		0122												
	S	678	0173												
	M														
	A		0178	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		700	0280	■	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		720	0112	X	X	X	X	X	X	X	X	X	X	X	X
			0227	X	X	X	X	X	X	X	X	X	■	X	X
ALTA LAKE	A	741													
	M		0251	X	X	X	X	X	X	X	X	X	X	X	X
	S		0264												
	S	746	0245												
	M														
	A		0294	X	X	X	X	X	X	X	X	X	X	X	X
MONS	A	764	0137	X	X	X	X	X	X	X	X	X	X	X	X
	M		0116	X	X	X	X	X	X	X	X	X	X	X	X
	S		0155												
	S	778	0272												
	M		0170	X	X	X	X	X	X	X	X	X	X	X	X
	A		0103	X	X	X	X	X	X	X	X	X	X	X	X

EXAMPLE OF RAW TRANSPONDER DATA USED TO COMPILE BASIC TRACKING TRANSPONDER SUMMARY

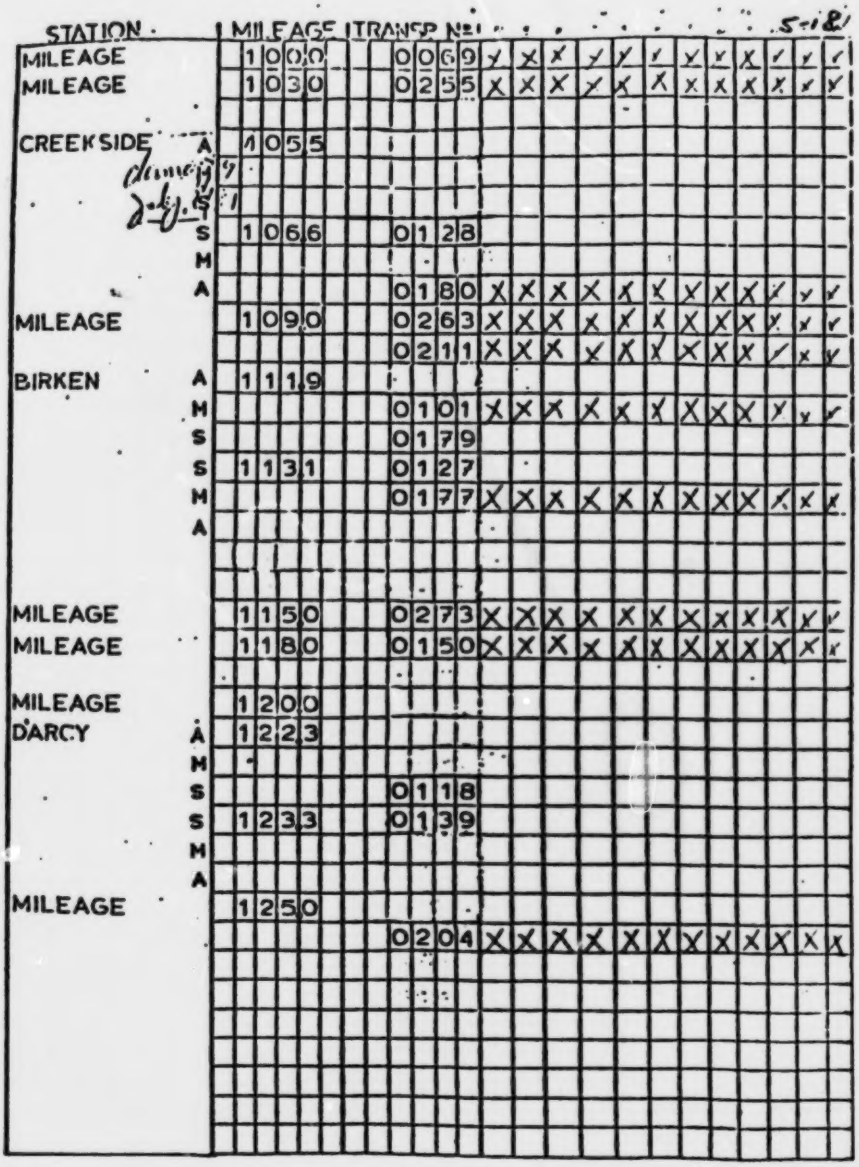
FIGURE (c)



STATION		MILEAGE	TRANSP Nº												5-7
MILEAGE		820	0218	X	✓	X	X	X	✓	✓	X	X	X	✓	✓
			0268	X	X	X	X	X	✓	X	X	X	X	✓	✓
MILEAGE		850													
MILEAGE		860	0299	✓	■	X	X	■	✓	✓	X	X	X	✓	X
			0232	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		880													
TISDALL	A	896	0131	X	X	X	X	■	✓	X	X	X	X	✓	■
	M		0134	X	X	X	X	X	X	X	X	X	X	X	X
	S		0157												
	S	909													
	M		0165	X	X	X	X	■	✓	X	■	X	X	X	■
	A		0296	X	X	X	X	X	X	X	X	X	X	✓	✓
MILEAGE		930	0218	X	X	X	X	X	X	X	X	X	X	X	X
			0223	X	X	X	X	X	X	■	X	X	X	X	X
PEMBERTON	A	943													
	M														
	S		0286												
WYE SOUTH		944													
			0226												
WYE NORTH		946	0217												
			0253												
PEMBERTON	S	950	0174												
	M														
	A		0071	X	X	X	✓	X	✓	X	X	X	X	X	X
MILEAGE		970	0200	X	X	X	X	X	X	X	■	X	X	■	X
EVANS	A	987	0285	X	X	X	X	X	X	X	X	X	X	X	X
	M		0237	✓	X	X	X	X	X	X	X	X	X	X	X
	S		0258												
	S	989	0270												
	M														
	A														

EXAMPLE OF RAW TRANSPONDER DATA USED TO COMPILE BASIC TRACKING TRANSPONDER SUMMARY

FIGURE (d)

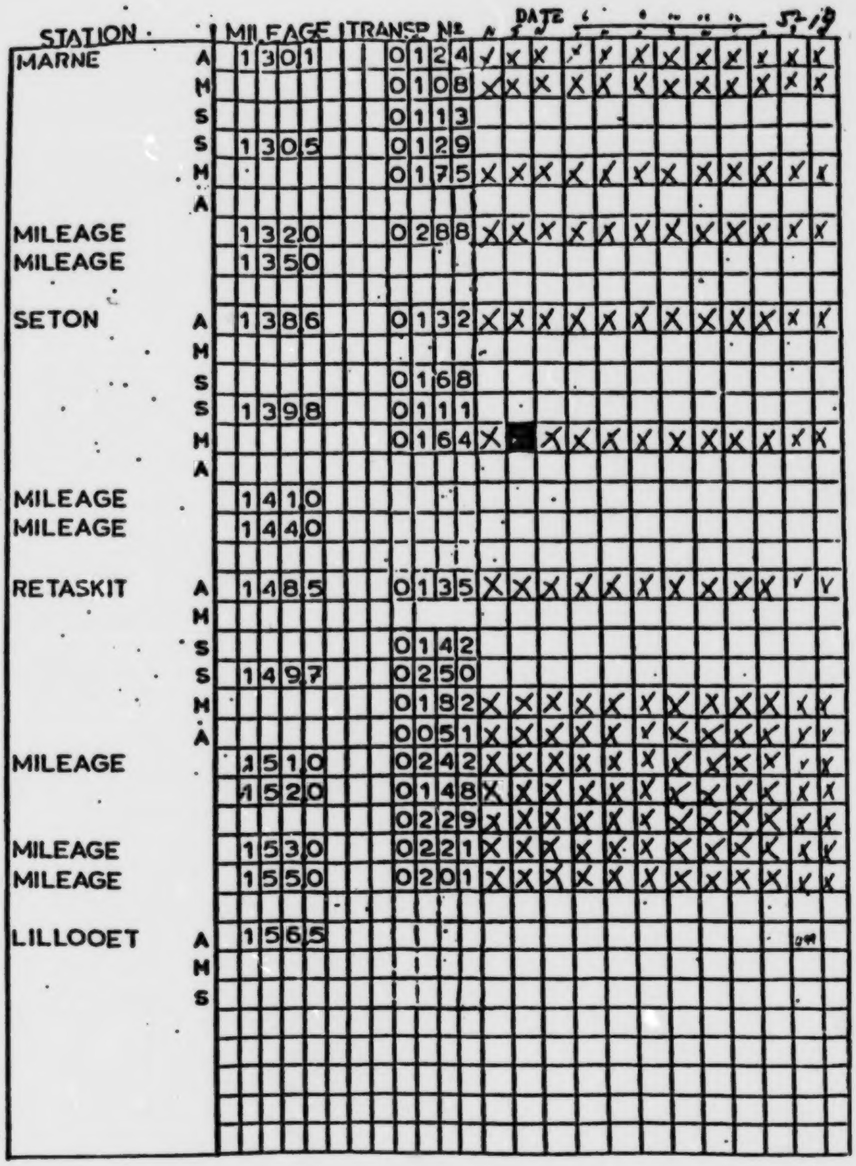


5-18/

STATION		MILEAGE	TRANSP No												
MILEAGE		100.0	0069	✓	X	X	✓	✓	✓	✓	✓	X	✓	✓	✓
MILEAGE		103.0	0255	X	X	X	✓	X	X	X	X	X	X	✓	✓
CREEKSIDE	A	1055													
[illegible] 7															
[illegible] 5 1															
	S	106.6	0128												
	M														
	A		0180	X	X	X	X	X	X	✓	X	X	✓	✓	✓
MILEAGE		109.0	0263	X	X	X	X	✓	X	X	X	X	✓	✓	✓
			0211	X	X	X	✓	X	X	X	X	X	✓	X	✓
BIRKEN	A	111.9													
	M		0101	X	X	X	X	X	X	X	X	X	✓	✓	✓
	S		0179												
	S	113.1	0127												
	M		0177	X	X	X	X	X	X	X	X	X	X	X	✓
	A														
MILEAGE		115.0	0273	X	X	X	X	X	X	X	X	X	X	✓	✓
MILEAGE		118.0	0150	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		120.0													
D'ARCY	A	122.3													
	M														
	S		0118												
	S	123.3	0139												
	M														
	A														
MILEAGE		125.0													
			0204	X	X	X	X	X	X	X	X	X	X	X	X

EXAMPLE OF RAW TRANSPONDER DATA USED TO COMPILE BASIC TRACKING TRANSPONDER SUMMARY

FIGURE (e)



STATION		MILEAGE	TRANSP Nº	DATE											
MARNE	A	1301	0124	✓	X	X	X	X	X	X	X	X	X	X	X
	M		0108	X	X	X	X	X	X	X	X	X	X	X	X
	S		0113												
	S	1305	0129												
	M		0175	X	X	X	X	X	X	X	X	X	X	X	X
	A														
MILEAGE		1320	0288	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		1350													
SETON	A	1386	0132	X	X	X	X	X	X	X	X	X	X	X	X
	M														
	S		0168												
	S	1398	0111												
	M		0164	X	[illegible]	X	X	X	X	X	X	X	X	X	X
	A														
MILEAGE		1410													
MILEAGE		1440													
RETASKIT	A	1485	0135	X	X	X	X	X	X	X	X	X	X	✓	✓
	M														
	S		0142												
	S	1497	0250												
	M		0182	X	X	X	X	X	X	X	X	X	X	X	X
	A		0051	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		1510	0242	X	X	X	X	X	X	X	X	X	X	X	X
		1520	0148	X	X	X	X	X	X	X	X	X	X	X	X
			0229	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		1530	0221	X	X	X	X	X	X	X	X	X	X	X	X
MILEAGE		1550	0201	X	X	X	X	X	X	X	X	X	X	X	X
LILLOOET	A	1565												on	
	M														
	S														

EXAMPLE OF RAW TRANSPONDER DATA USED TO COMPILE BASIC TRACKING TRANSPONDER SUMMARY

FIGURE (f)

APPENDIX E

ODOMETER CALIBRATION GRAPHS

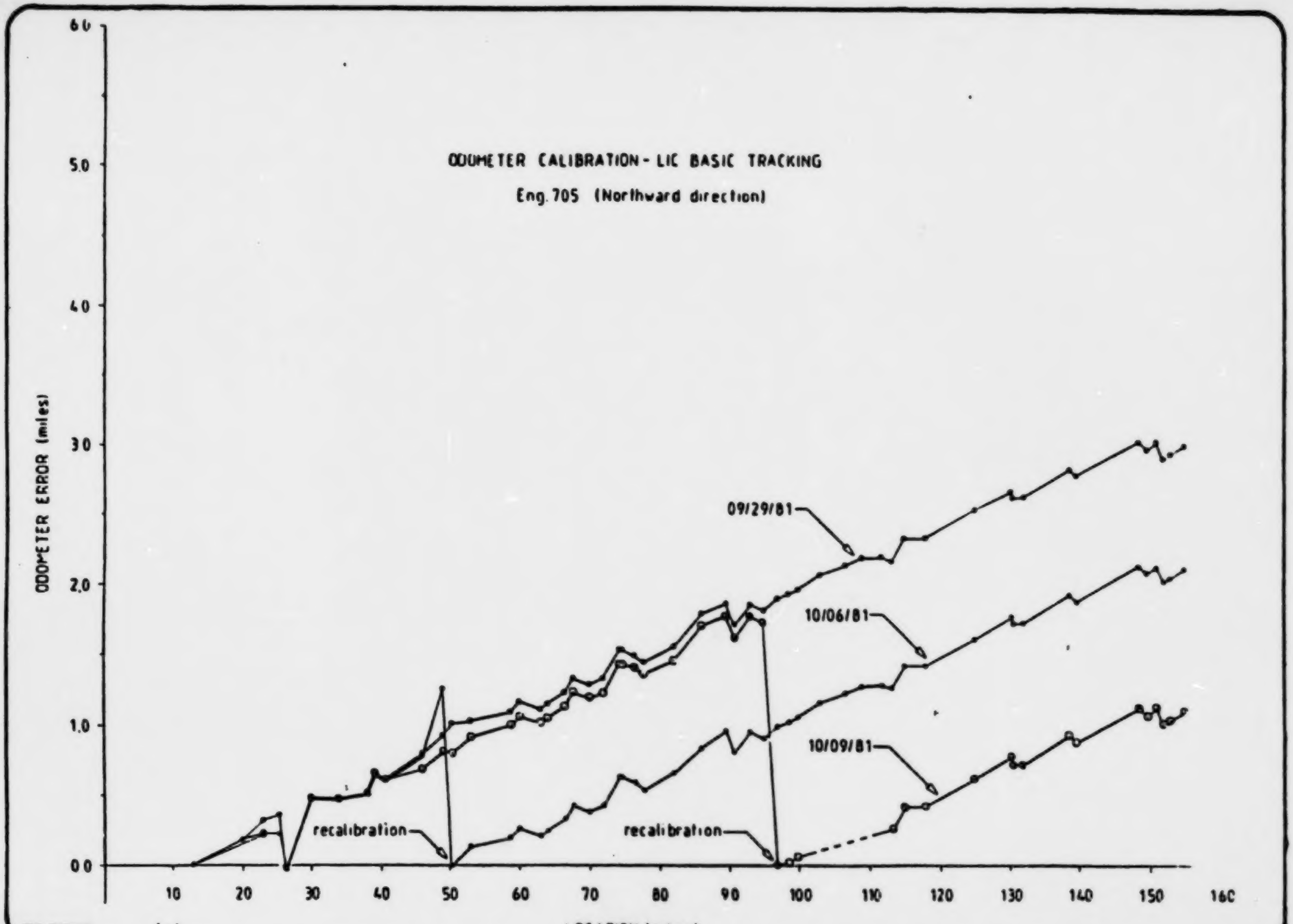
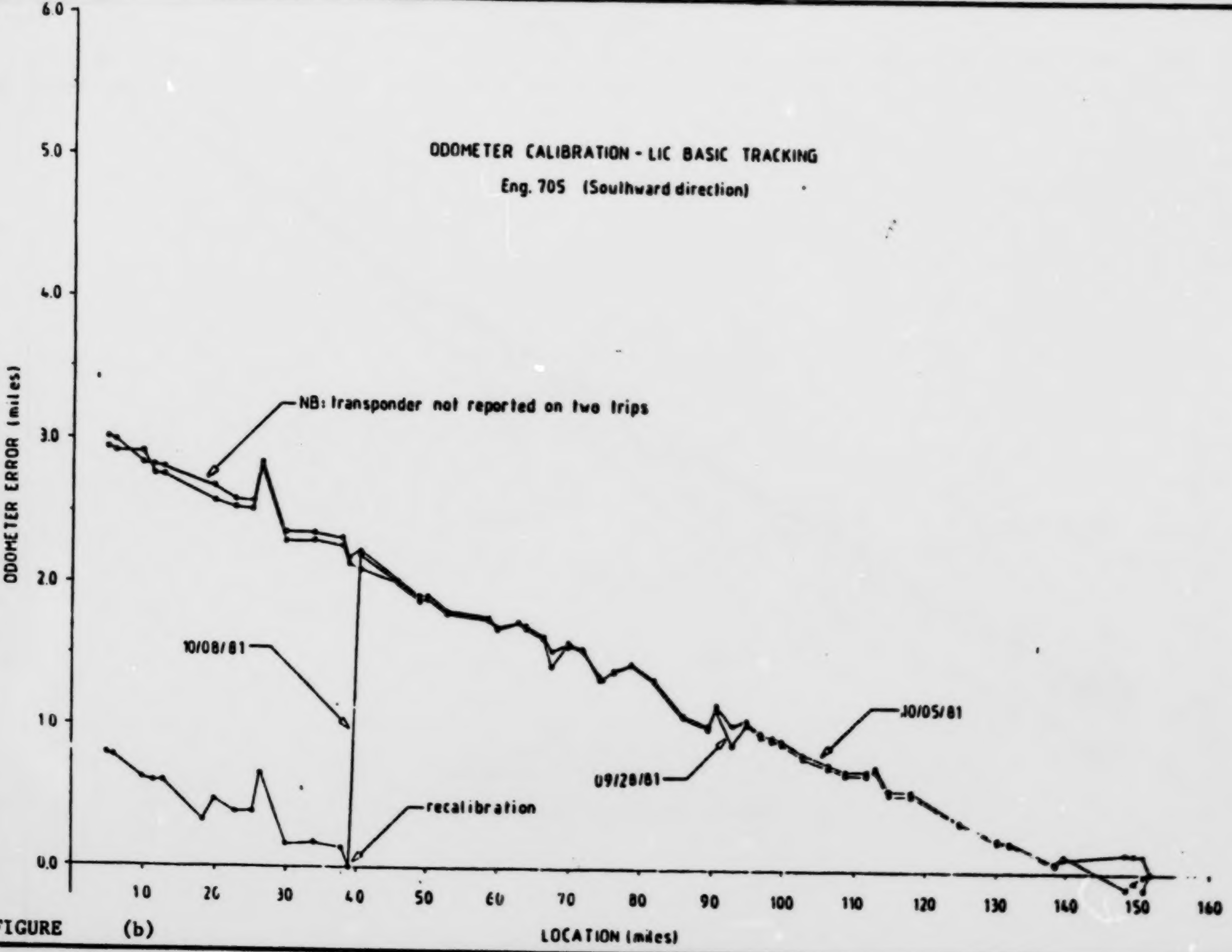

ODOMETER CALIBRATION - LIC BASIC TRACKING
Eng. 705 (Northward direction)
ODOMETER ERROR (miles)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
09/29/81
10/06/81
10/09/81
recalibration
recalibration
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
LOCATION (miles)

FIGURE (a)



ODOMETER CALIBRATION - LIC BASIC TRACKING

Eng. 705 (Southward direction)

FIGURE (b)

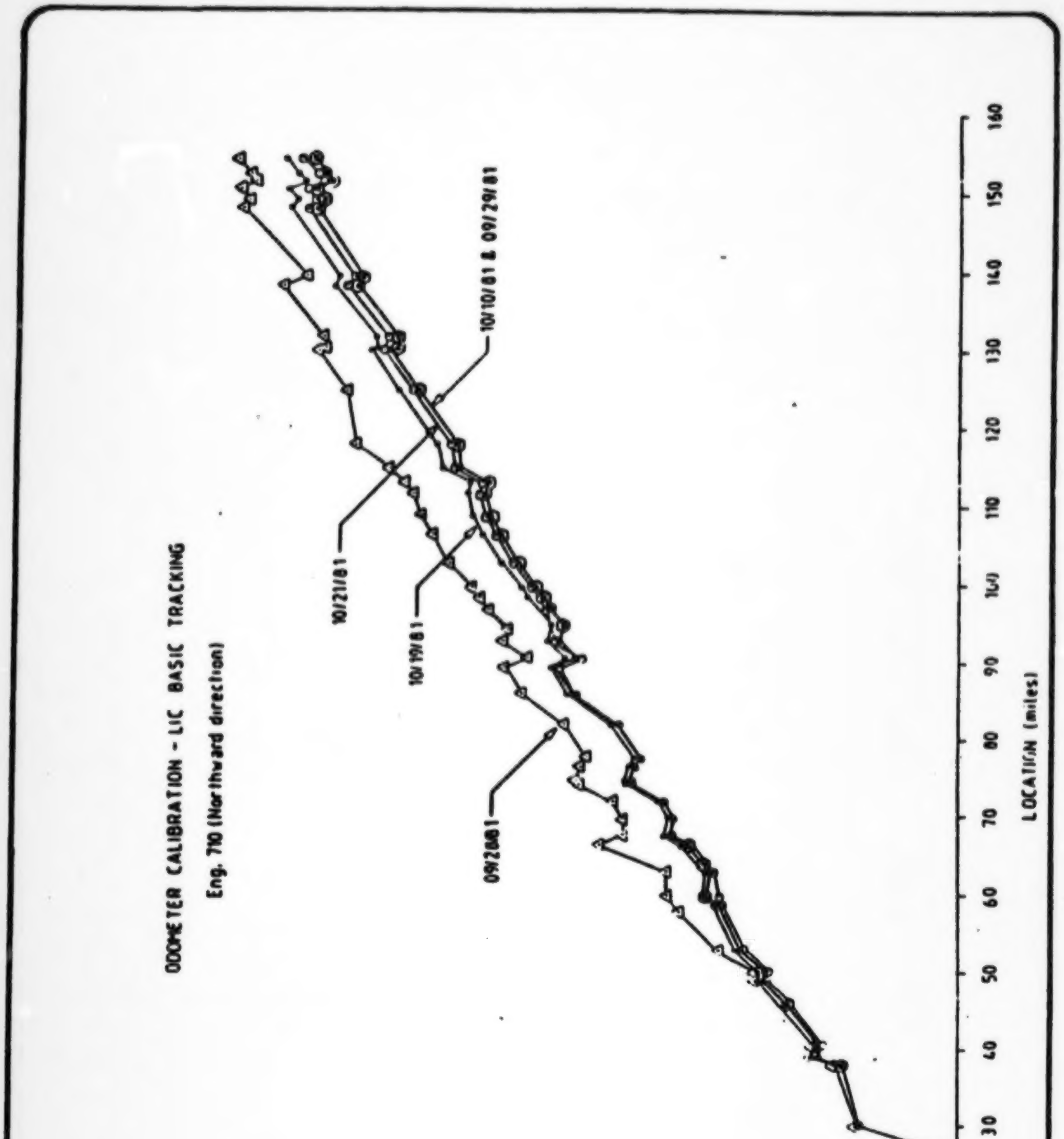

ODOMETER CALIBRATION - LIC BASIC TRACKING
Eng. 710 (Northward direction)
10/10/81 & 09/29/81
10/21/81
10/19/81
09/28/81
ODOMETER ERROR (miles)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
LOCATION (miles)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

FIGURE (c)

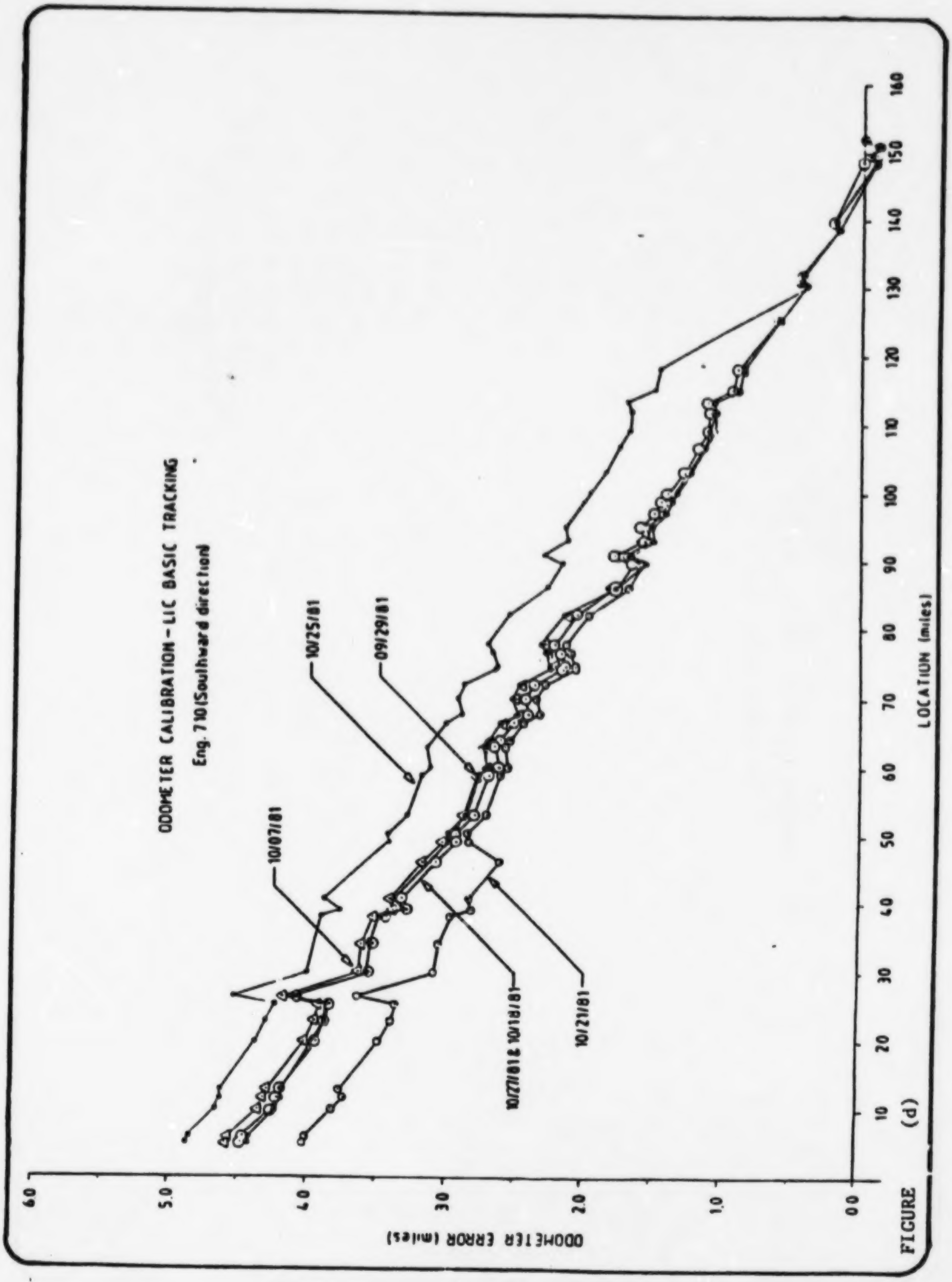
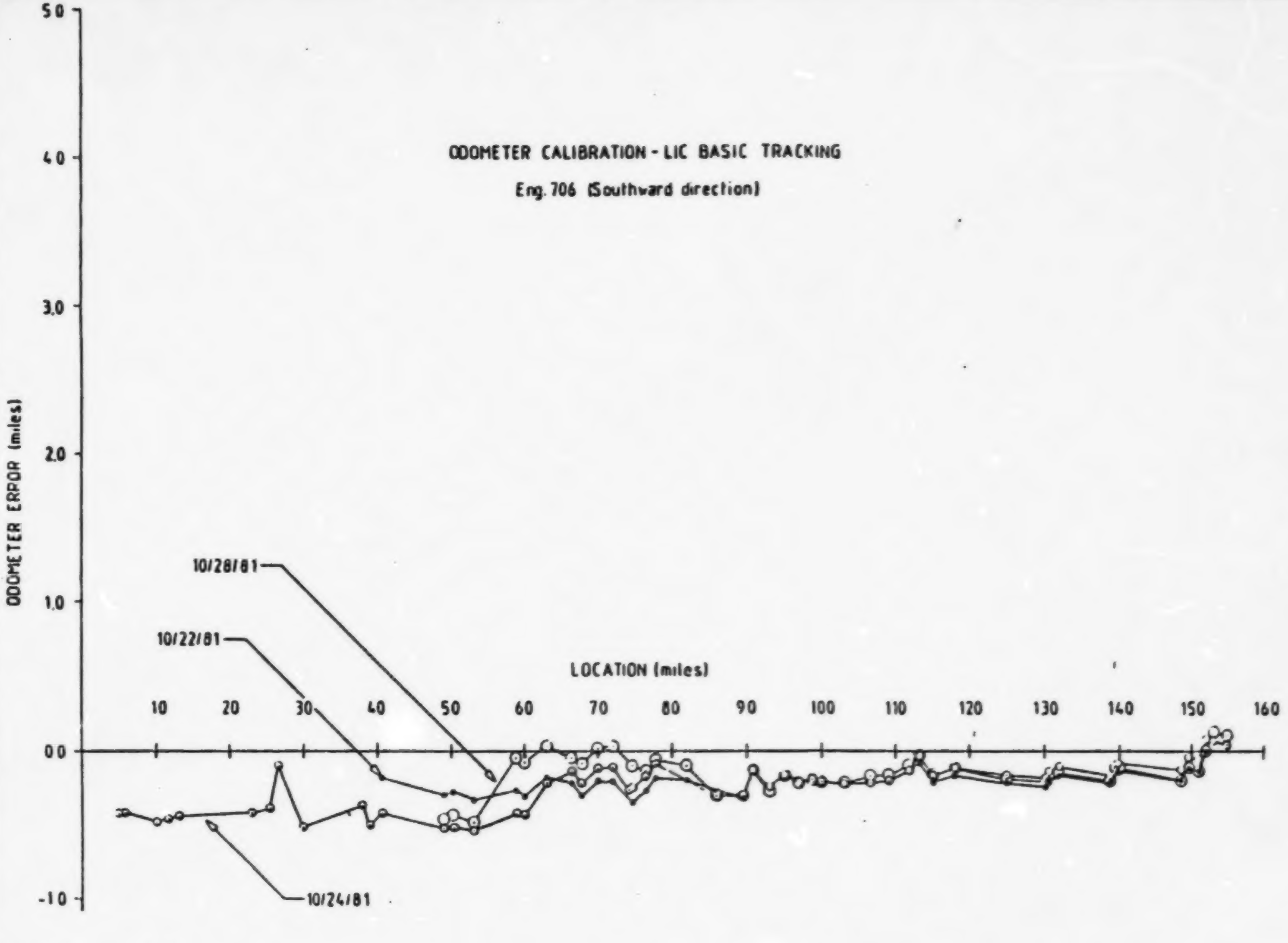

ODOMETER CALIBRATION - LIC BASIC TRACKING
Eng. 710 (Southward direction)
ODOMETER ERROR (miles)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
LOCATION (miles)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
10/07/81
10/25/81
09/29/81
10/27/81 & 10/18/81
10/21/81

FIGURE (d)


ODOMETER CALIBRATION - LIC BASIC TRACKING

Eng. 706 (Southward direction)

FIGURE (e)

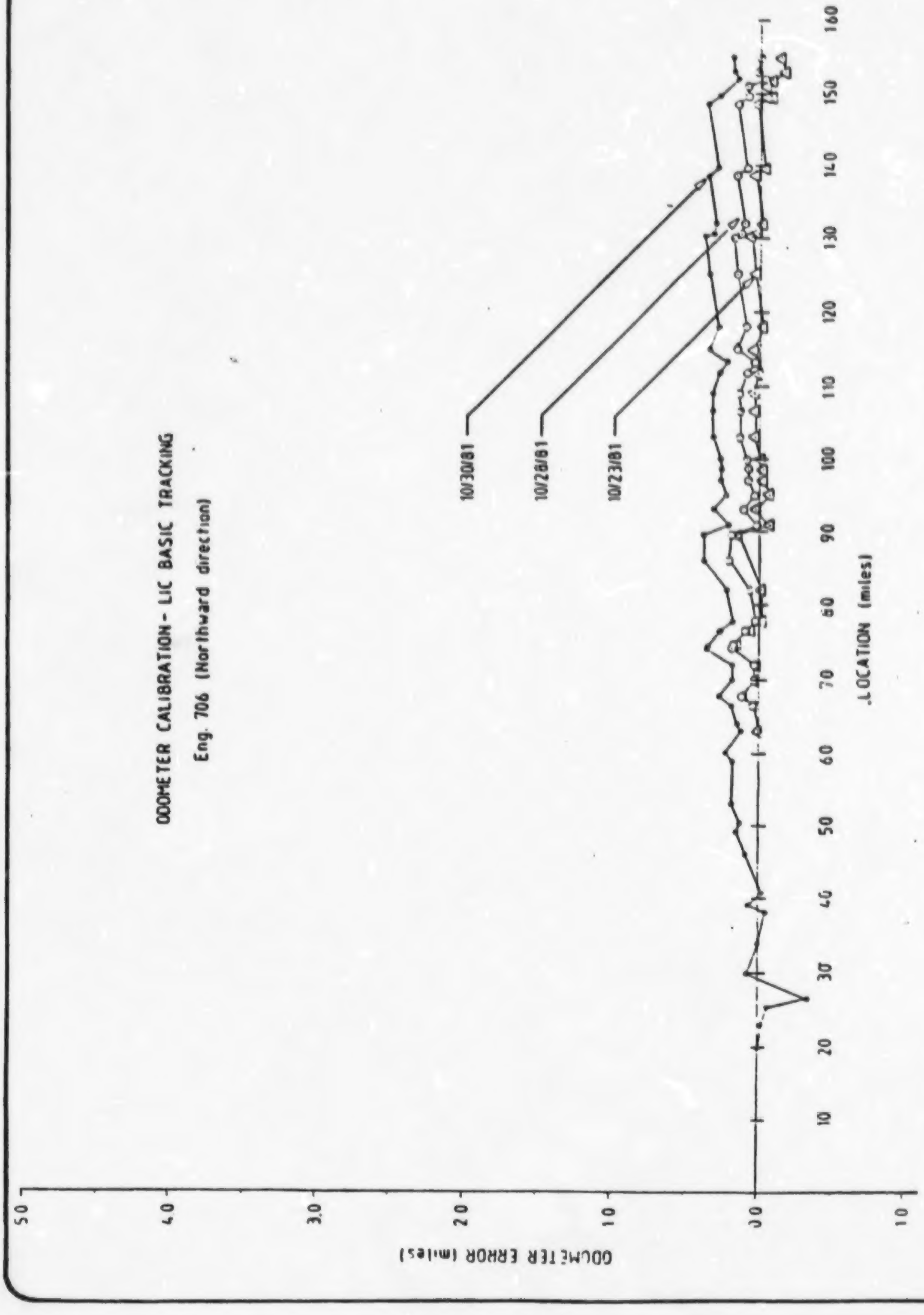
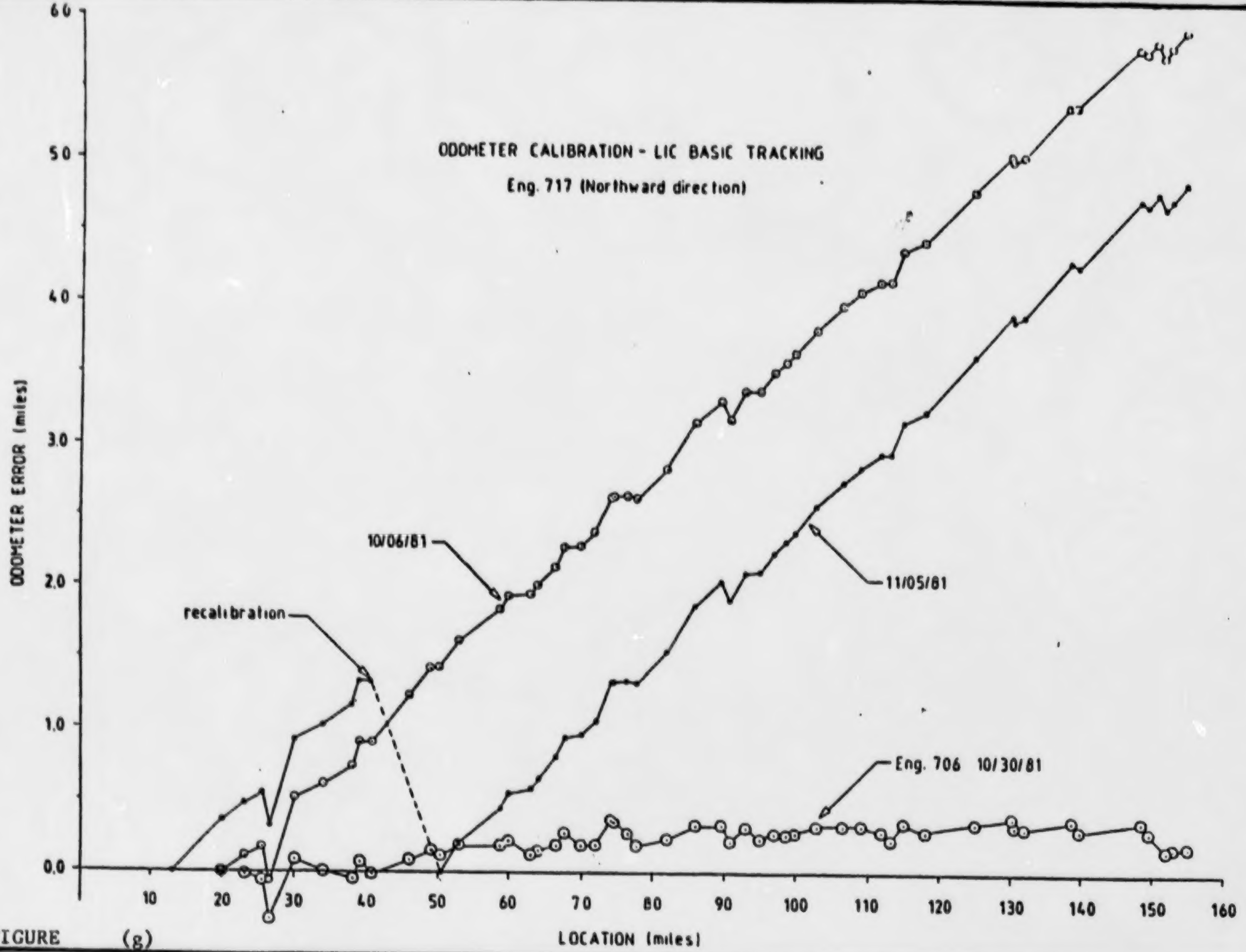

ODOMETER CALIBRATION - LIC BASIC TRACKING
Eng. 706 (Northward direction)
10/30/81
10/28/81
10/23/81
ODOMETER ERROR (miles)
5.0
4.0
3.0
2.0
1.0
0.0
1.0
LOCATION (miles)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

FIGURE (f)



ODOMETER CALIBRATION - LIC BASIC TRACKING

Eng. 717 (Northward direction)

FIGURE (g)

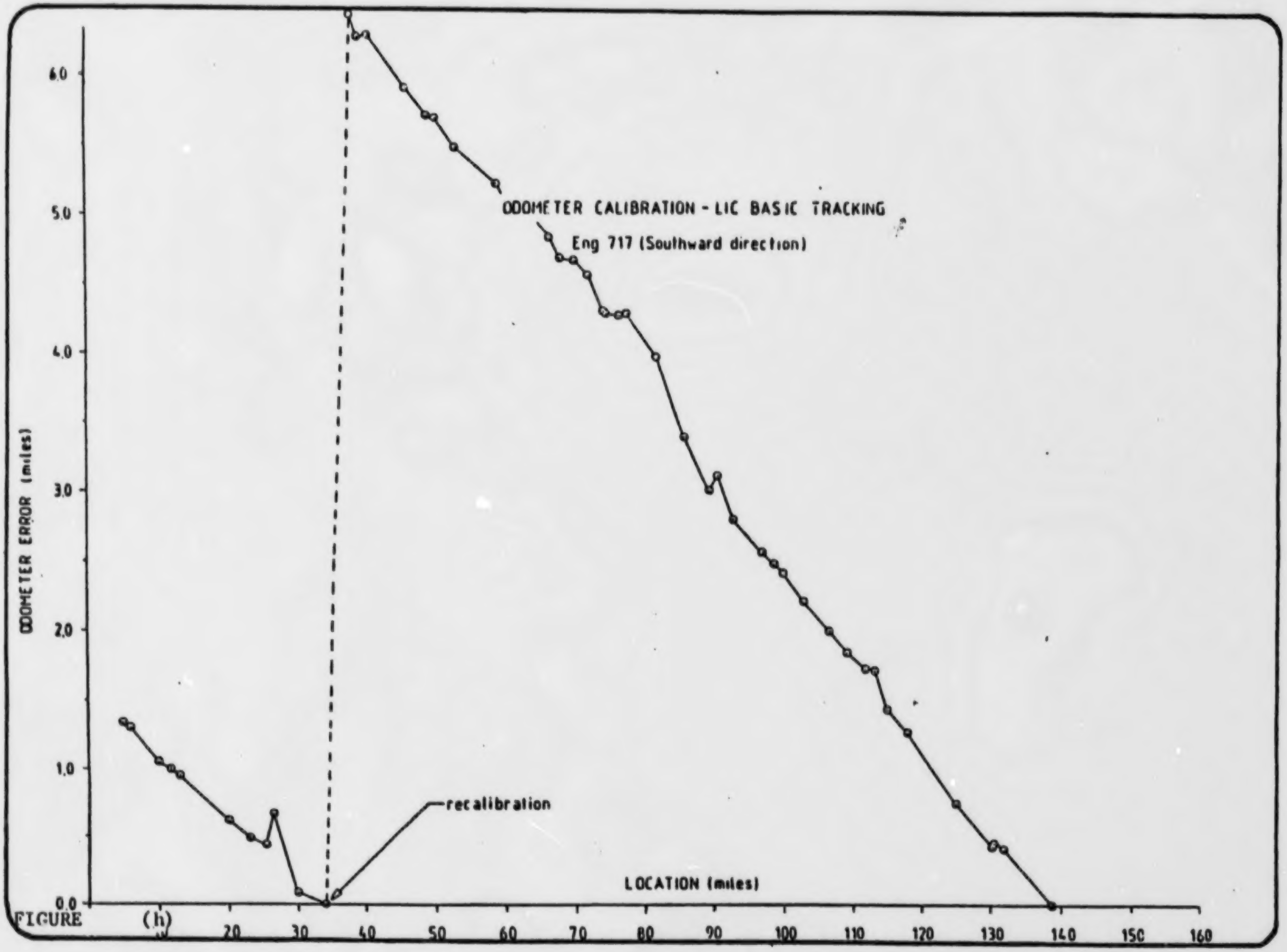


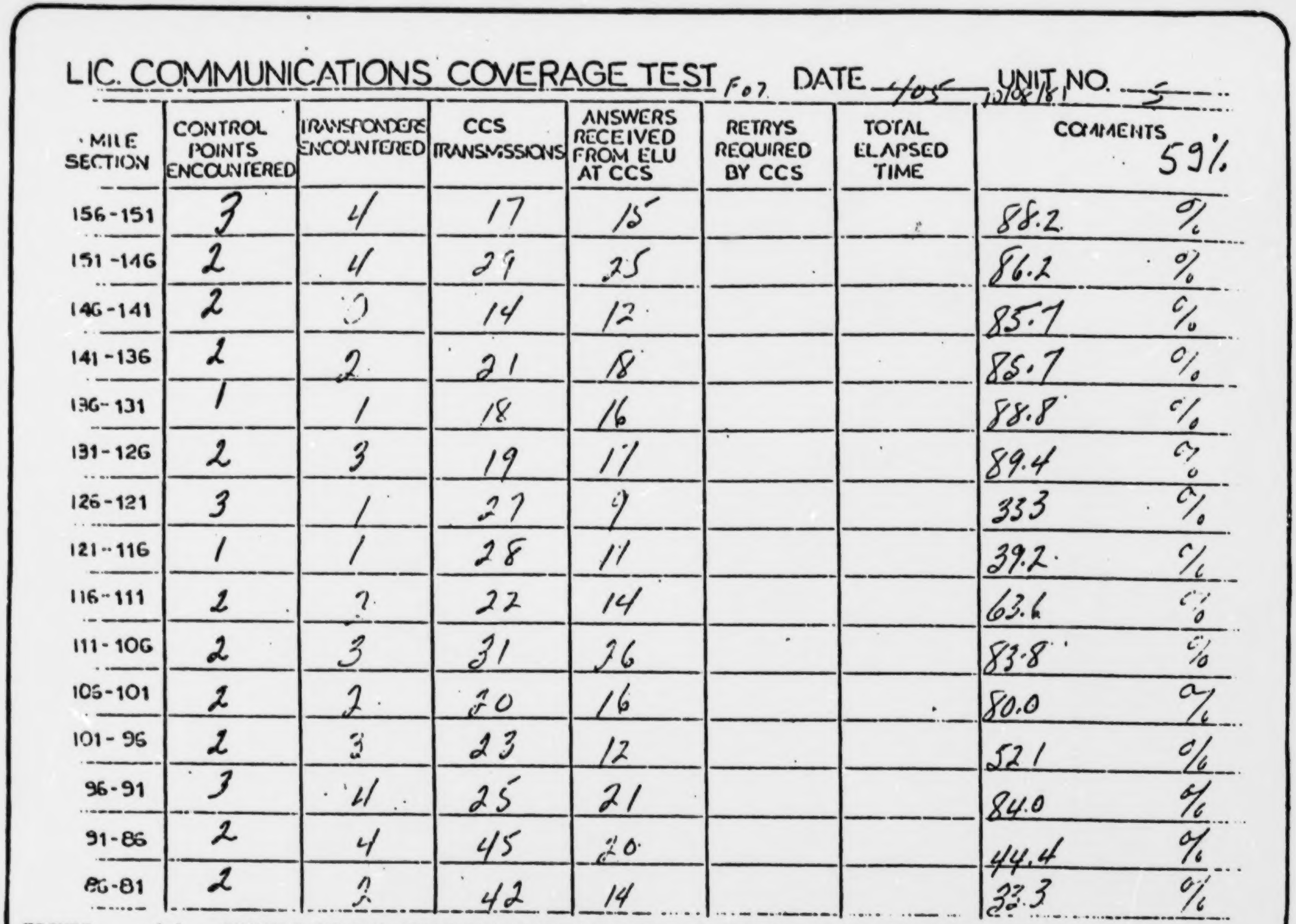
FIGURE (h)

ODOMETER CALIBRATION - LIC BASIC TRACKING

Eng 717 (Southward direction)

APPENDIX F

SAMPLE OF INDIVIDUAL COMMUNICATIONS TRIP REPORTS FOR BASIC TRACKING



LIC. COMMUNICATIONS COVERAGE TEST F07 DATE 405 10/08/81 UNIT NO. 5

MILE SECTION	CONTROL POINTS ENCOUNTERED	TRANSPONDERS ENCOUNTERED	CCS TRANSMISSIONS	ANSWERS RECEIVED FROM ELU AT CCS	RETRYS REQUIRED BY CCS	TOTAL ELAPSED TIME	COMMENTS 59%
156-151	3	4	17	15			88.2 %
151-146	2	4	29	25			86.2 %
146-141	2	0	14	12			85.7 %
141-136	2	2	21	18			85.7 %
136-131	1	1	18	16			88.8 %
131-126	2	3	19	17			89.4 %
126-121	3	1	27	9			33.3 %
121-116	1	1	28	11			39.2 %
116-111	2	2	22	14			63.6 %
111-106	2	3	31	26			83.8 %
106-101	2	2	20	16			80.0 %
101-96	2	3	23	12			52.1 %
96-91	3	4	25	21			84.0 %
91-86	2	4	45	20			44.4 %
86-81	2	2	42	14			33.3 %

FIGURE (a) EXAMPLE OF RAW COMMUNICATIONS DATA USED TO COMPILE BASIC TRACKING COMMUNICATION SUMMARY

LIC. COMMUNICATIONS COVERAGE TEST F 6 DATE [illegible] UNIT NO. 405 -N

MILE SECTION	CONTROL POINTS ENCOUNTERED	TRANSPONDERS ENCOUNTERED	CCS TRANSMISSIONS	ANSWERS RECEIVED FROM ELU AT CCS	RETRYS REQUIRED BY CCS	TOTAL ELAPSED TIME	COMMENTS 59%
156-151	3	6	38	33			86.8 %
151-146	2	1	33	31			93.9 %
146-141	2	1	51	38			74.5 %
141-136	2	2	41	37			90.2 %
136-131	1	3	31	31			100 %
131-126	2	1	31	27			87.0 %
126-121	3	6	31	23			74.1 %
121-116	1	2	34	20			58.8 %
116-111	2	2	38	34			89.4 %
111-106	2	3	31	25			80.6 %
106-101	2	2	32	24			75.0 %
101-96	2	4	31	25			80.6 %
96-91	3	5	45	37			82.2 %
91-86	2	4	72	23			31.9 %
86-81	2	2	65	21			32.3 %
81-76	1	4	30	28			93.3 %

FIGURE (b) EXAMPLE OF RAW COMMUNICATIONS DATA USED TO COMPILE BASIC TRACKING COMMUNICATION SUMMARY

LIC. COMMUNICATIONS COVERAGE TEST

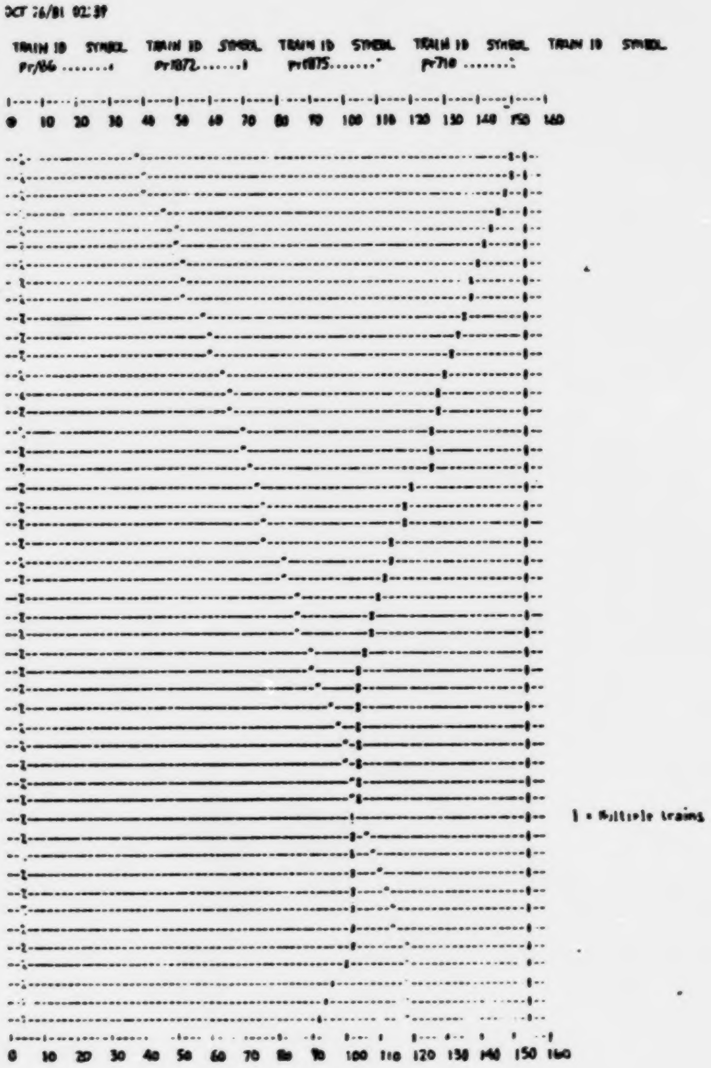
F S DATE [illegible] UNIT NO. [illegible]

5 MILE SECTION	CONTROL POINTS ENCOUNTERED	TRANSPONDERS ENCOUNTERED	CCS TRANSMISSIONS	ANSWERS RECEIVED FROM ELU AT CCS	RETRYS REQUIRED BY CCS	TOTAL ELAPSED TIME	COMMENTS 66%
156-151	3	4	119	113			94.9 %
151-146	2	4	19	18			[illegible] %
146-141	2	0	14	13			92.8 %
141-136	2	2	21	17			80.9 %
136-131	1	0	16	14			87.5 %
131-126	2	4	19	18			94.7 %
126-121	3	1	21	09			42.8 %
121-116	1	1	21	11			52.3 %
116-111	2	3	19	13			68.4 %
111-106	2	[illegible]	18	15			83.3 %
106-101	2	2	16	14			87.5 %
101-96	2	3	22	10			45.4 %
96-91	3	[illegible]	19	15			78.9 %
91-86	2	4	39	16			41.0 %
86-81	3	2	31	15			48.3 %

FIGURE (c) EXAMPLE OF RAW COMMUNICATIONS DATA USED TO COMPILE BASIC TRACKING COMMUNICATION SUMMARY

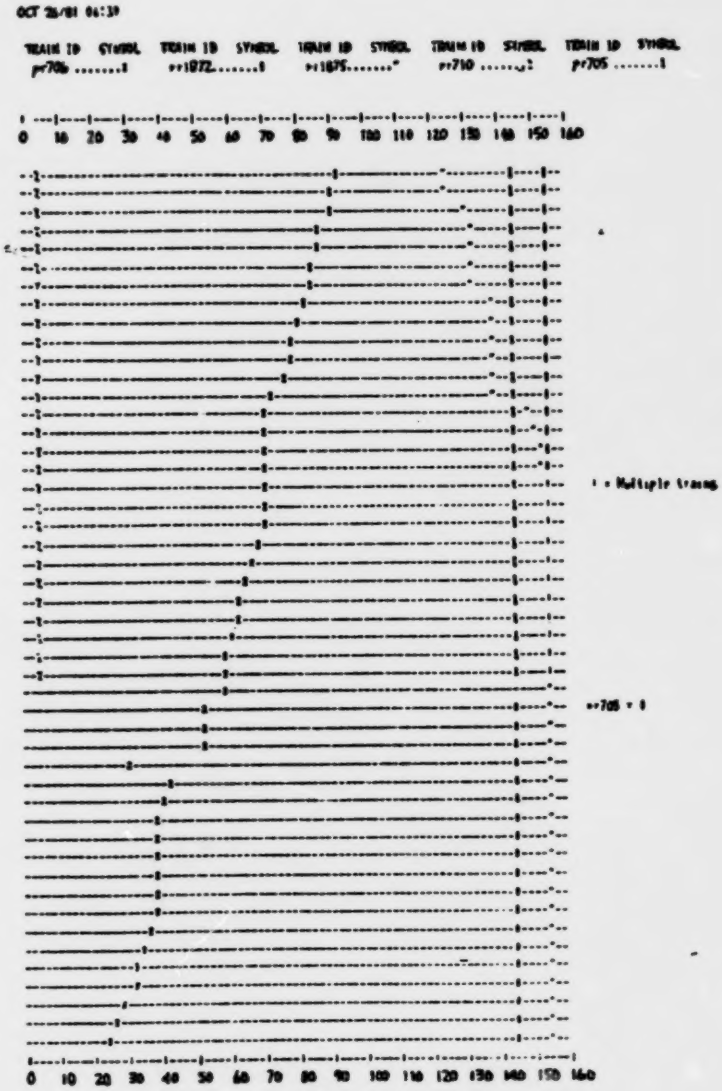
APPENDIX G

EXAMPLES OF TRAINGRAPH PRINTOUT



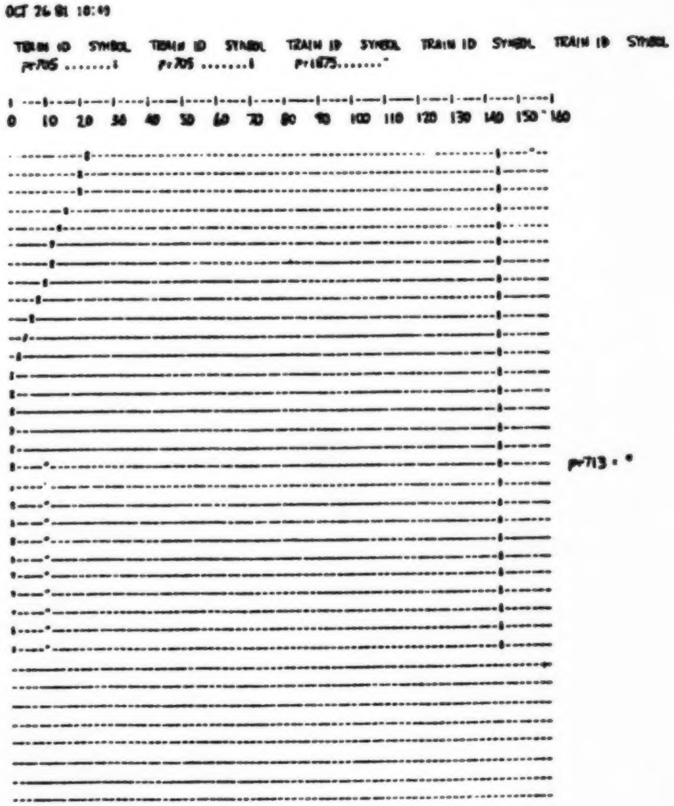
EXAMPLE OF DCP TRAIN GRAPH PERFORMANCE DURING BASIC TRACKING

FIGURE (a)



EXAMPLE OF DCP TRAIN GRAPH
PERFORMANCE DURING BASIC TRACKING

FIGURE (b)

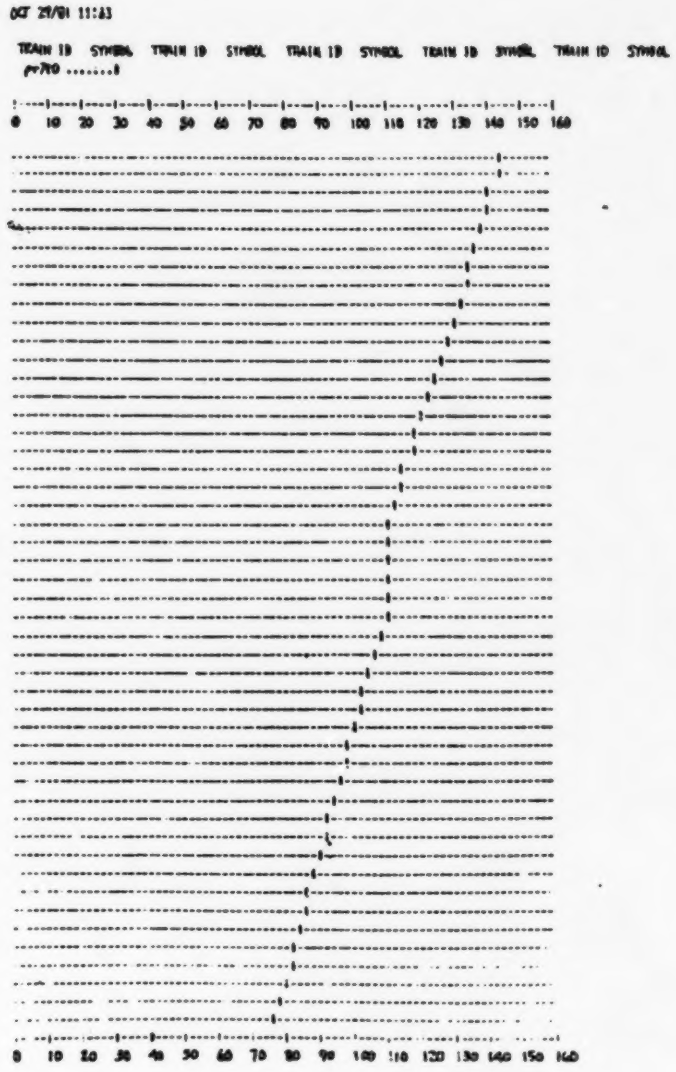


```
OCT 26 81 10:49

 TRAIN ID  SYMBOL  TRAIN ID  SYMBOL  TRAIN ID  SYMBOL  TRAIN ID  SYMBOL  TRAIN ID  SYMBOL
  pr705 .......I    pr705 .......I    pr1675.......*
```

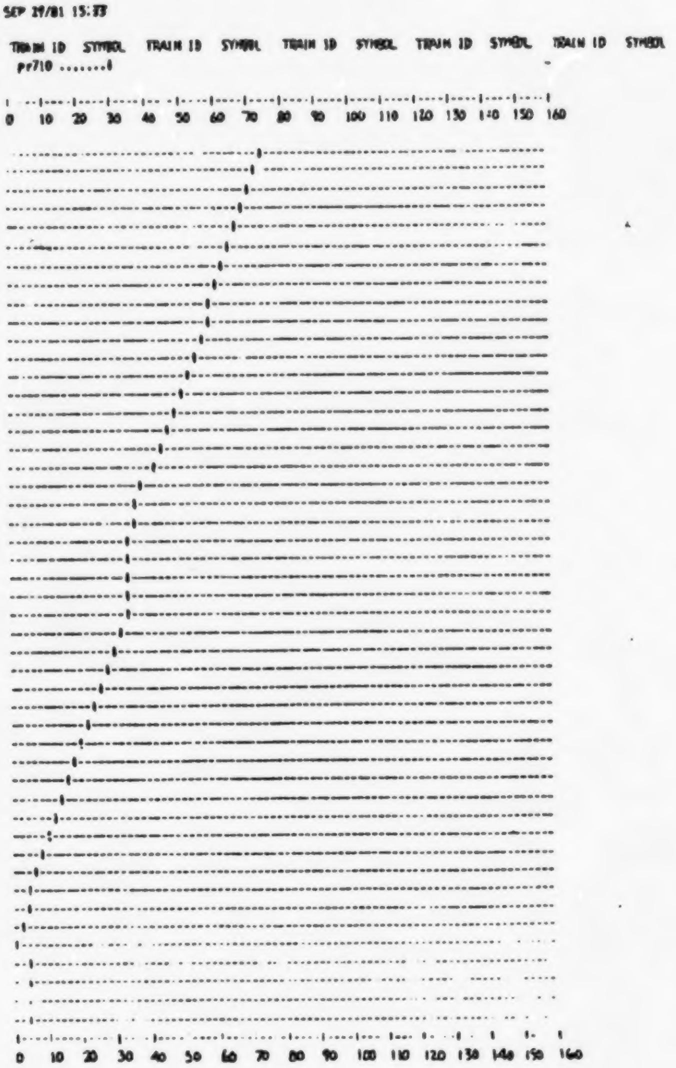
EXAMPLE OF DCP TRAIN GRAPH
PERFORMANCE DURING BASIC TRACKING

FIGURE (c)



EXAMPLE OF DCP TRAIN GRAPH
PERFORMANCE DURING BASIC TRACKING

FIGURE (d)



```
SEP 29/81 15:33

TRAIN ID  SYMBOL  TRAIN ID  SYMBOL  TRAIN ID  SYMBOL  TRAIN ID  SYMBOL  TRAIN ID  SYMBOL
 pr710 .......I
```

EXAMPLE OF DCP TRAIN GRAPH
PERFORMANCE DURING BASIC TRACKING

FIGURE (e)

APPENDIX H

BASIC TRACKING LIC SYSTEM LOAD TEST

LIC SYSTEM LOAD TEST - BASIC TRACKING

Train: OV-3

Length: 5400 ft.

Left Lillooet: 1955 K November 4, 1981

Equipment Used: Units 710 and 717 with head end power. Unit 706 with remote power.

Cabooses: 1870, 1875 and 1872 on rear of train.

Cycle: Set to 5 seconds.

All ELU spoke up via Mission and reported.

Crossing transponder south of Lillooet in a normal manner until tests started, with the exception of caboose 1870 failed after crossing transponder 135 at mile 148.5 due to dead batteries.

Test 1 (Cycle Set at 5 Seconds)

Time	Mile	
20:47:37	140.7	Disabled Communications Channel and Equipment Deleted
20:52:17	139.2	Restored Communications Channel
20:52:17		Speak Up From 717 - 4:40 Down Time
20:52:25		Speak Up From 710 - 4:46 Down Time
20:53:40		Speak Up From 706 - 5:03 Down Time
20:54:32		Speak Up From 1872 - 6:55 Down Time
20:54:44		Speak Up From 1875 - 7:07 Down Time
20:54:45		Five Transponders Encountered and Reported

FIGURE (a)

Test 2 (27 Transponders Reported)

20:56:22	Disabled Communications Channel and Equipment Deleted, Mile 138.2
21:11:15	Restored Communications Long Enough to Receive Speak Up - 706 and 1872 Train, Mile 134.6
21:11:15	Speak Up Received From 705, Down Time 15:09
21:11:25	Speak Up Received From 1872, Down Time 15:19, Two Transponders Encountered and Reported
21:11:57	Deleted 706
21:12:09	Deleted 1872
21:37:35	Mile 124.1 Approximately, Communications Restored
21:37:35	Speak Up Received From 710, Mile 124.1, Down Time 42.03
21:37:52	Speak Up Received From 717, Mile 124.1, Down Time 42:03
21:40:30	Speak Up Received From 1872, Mile 123.5, Down Time 28:21
21:45:28	Speak Up Received From 1875, Mile 121.7, Down Time 47:06
21:55:25	Speak Up Received From 706, Mile 119.9, Down Time 43:28

FIGURE (b)

Test 3 (29 Transponders Reported)

22:16:00	Disabled Communications Channel Did Not Delete, Mile 113
22:24:00	Restored Communications Channel
22:26:13	Speak Up Received From 710 Via Spetch
22:26:16	Speak Up Received From 1875 Via Mission
22:26:41	Speak Up Received From 706 Via Spetch
22:26:59	Speak Up Received From 1872 Via Spetch
22:28:08	Speak Up Received From 717 Via Whistler

Because 1875 spoke up via Mission, polling was set to Mission and had to go into communications fail and speak up again at 22:41:54 via Whistler. Train at mileage 106.

22:36:00	Mile 108 Approximately, Communications Lost with 710 Via Mission
22:42:14	1875 Speaking Up Via Spetch
22:48:22	710 Speaking Up Via Pemberton Train MB 103.9

FIGURE (c)

Test 4 (17 Transponders Reported)

22:51:13	Disabled the Communications Channel, Train MB 102, No Deletions

Noted that it took from 22:53:13 until 22:54:23 to go through polling list, once Fringer area, Pemberton, and Spetch. DCP responses wait internal was set at approximately 2.08 seconds. The normal setting is 1.04 seconds.

22:24:03	Communications Restored
22:24:03	710 was Talked to From the Polling List
22:24:03	706 Speak Up Via Pemberton
22:24:22	717 was Talked to From the Polling List
22:24:50	1875 was Talked to From the Polling List
22:26:07	1872 was Talked to From the Polling List

Test 5 (6 Transponders Reported)

23:47:02	Disabled All Remote Sites - Cycle Set to 1 Second
23:55:29	Enabled Whistler A Only - Train at Mile 87

Between 23:55:29 and 00:01:02 none of the equipment went into communications fail but, neither the 706 nor 1875 were communicated with.

00:01:04	System Reset - Train at Mile 84.2 Approximately, Cycle Reset to 5 Seconds

FIGURE (d)

Test 6

01:21:52	Disabled Communications Channel, Train at MB 69.9
01:58:49	Communications Channel Restored

Train at MB 56 and because of tear in paper, the LA-120 sent a control 5 to the DCP. Due to buffer overflow, this crashed the DCP and the system had to be re-started.

Test 7 (7 Transponders Reported)

02:14:03	Disabled Communications Channel, Train at Mile 53 Approximately, Equipment was Not Deleted
02:21:39	Communications Channel Restored, Train at Mile 48 Approximately
02:21:39	717 Speak Up Via Watts
02:21:56	1872 Polled From Whistler
02:22:19	710 Polled From Whistler
02:22:34	706 Polled From Whistler
02:24:13	1875 Polled From Whistler

It was felt that all necessary tests were made and testing was terminated at this time.

FIGURE (e)

APPENDIX J

TRANSPONDER TESTS CARRIED OUT:

11 January, 1982
to
29 January, 1982

TRANSPONDER TESTS CARRIED OUT 11/1/82 - 19/1/82

1. Track plan: - All transponders shaded out are not in position at this moment in time.
   N.B. Transponder 070 at mile 15 was replaced with No. 020 on the 17th Jan.

2. Data samples ① - ⑫ cross refer to the filing of print-outs (Held by B.C.R.)

3. Key to symbols used on charts

↑ Transponder crossed in the direction indicated by the arrowhead, transponder data read without error.

✕ Transponder crossed in both directions as in switching moves, transponder data read without error.

▲ Transponder crossed in the direction indicated by the arrowhead, transponder data missed.

(4-2-9) No transponder crossed but ELU has read data but not accepted it. Transponder number refers to:

4 - error message
2 - error type (BCH error)
9 - number of frames (9 is maximum print of number but actual may be greater)

⋮ Solid connecting lines indicate continuity of trip where lines are dashed this indicates data before and after a loss is part of the same trip.

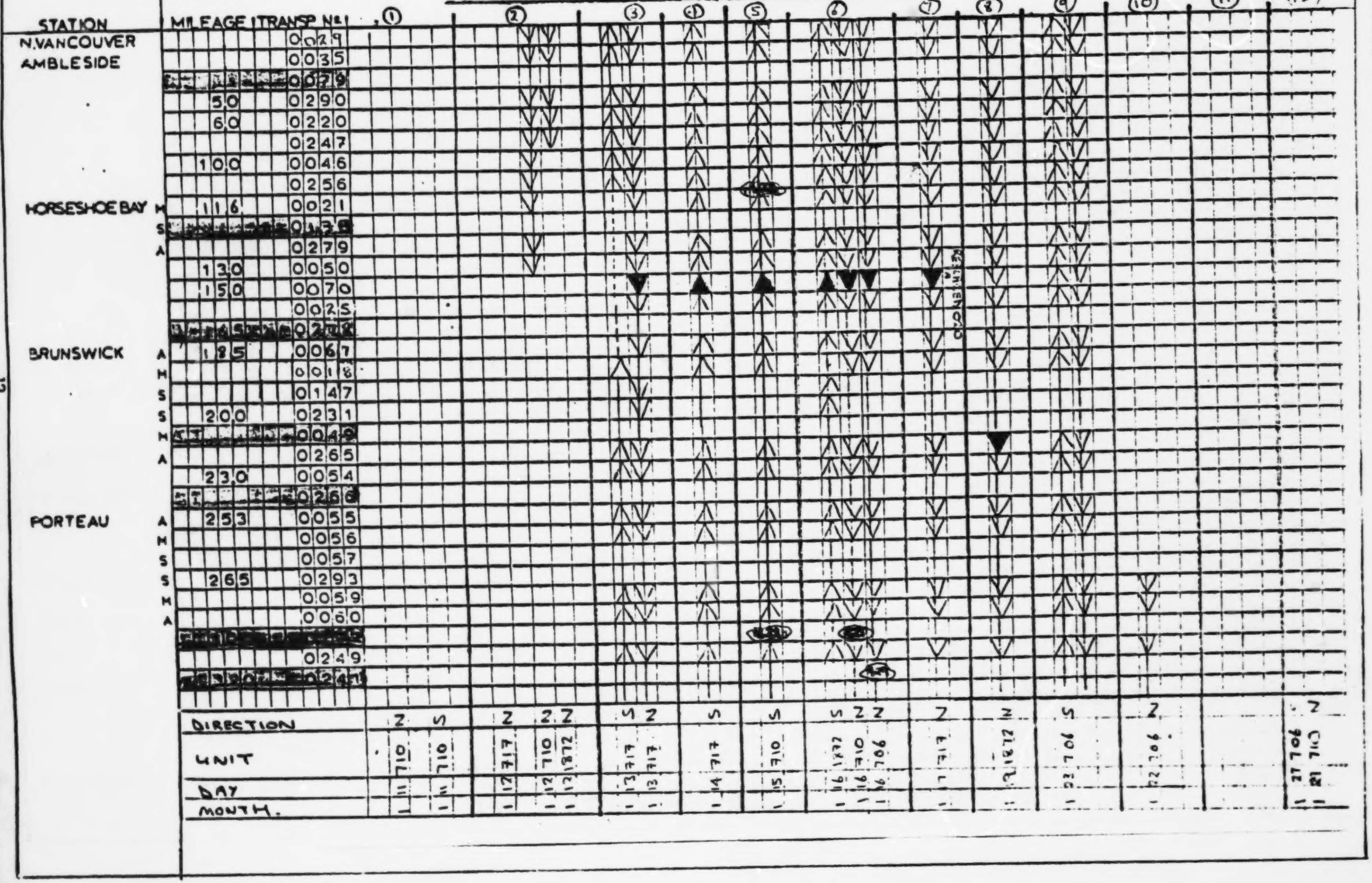
4. Summary of Results

Total number of transponder crossings	1262
Total number of transponders reported	1261
Capture Rate	99.92%

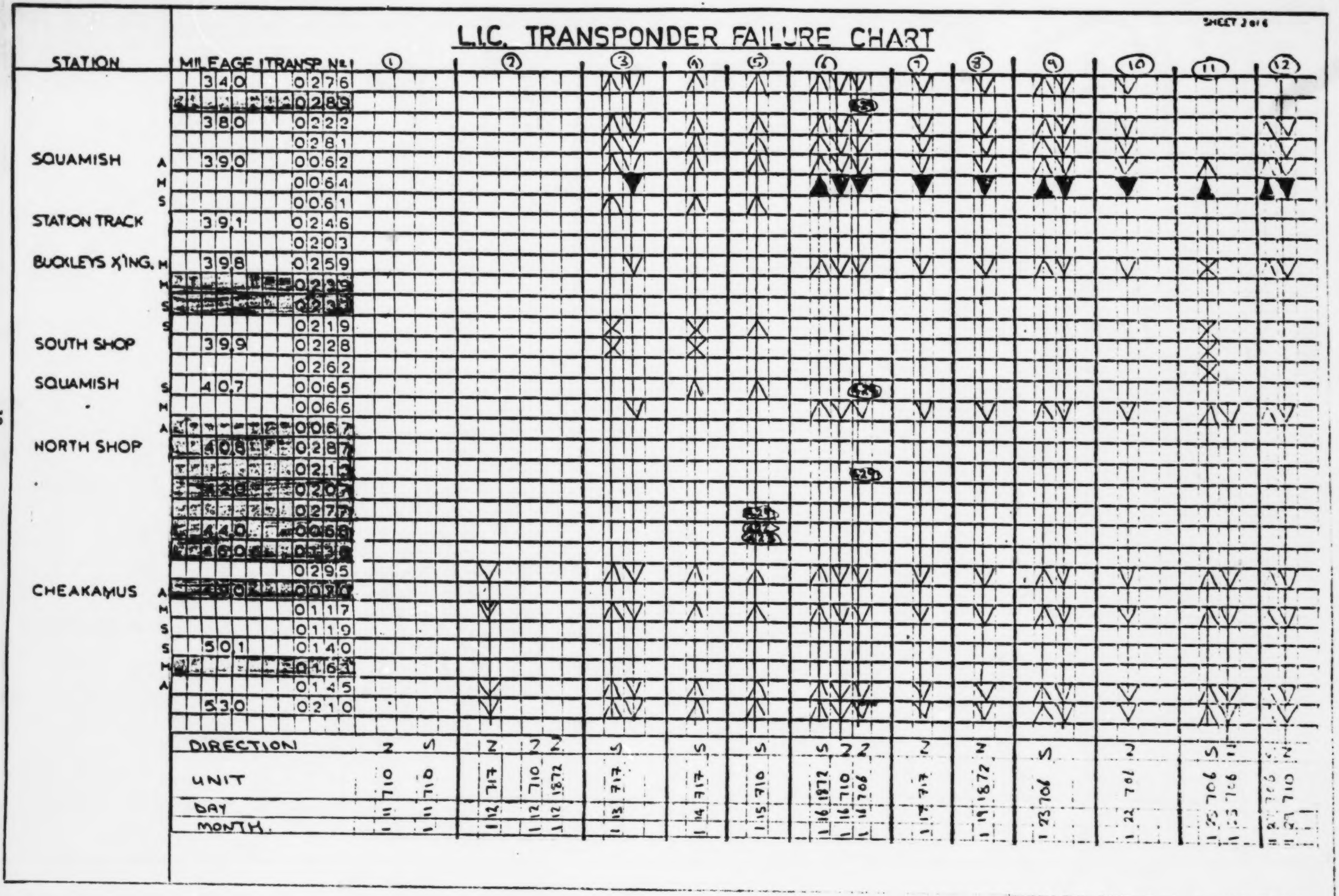
Note: transponders missed due to known failure or found to be missing are not included. Also transponders missed due to communications failure are excluded.

SHEET 1 OF 2

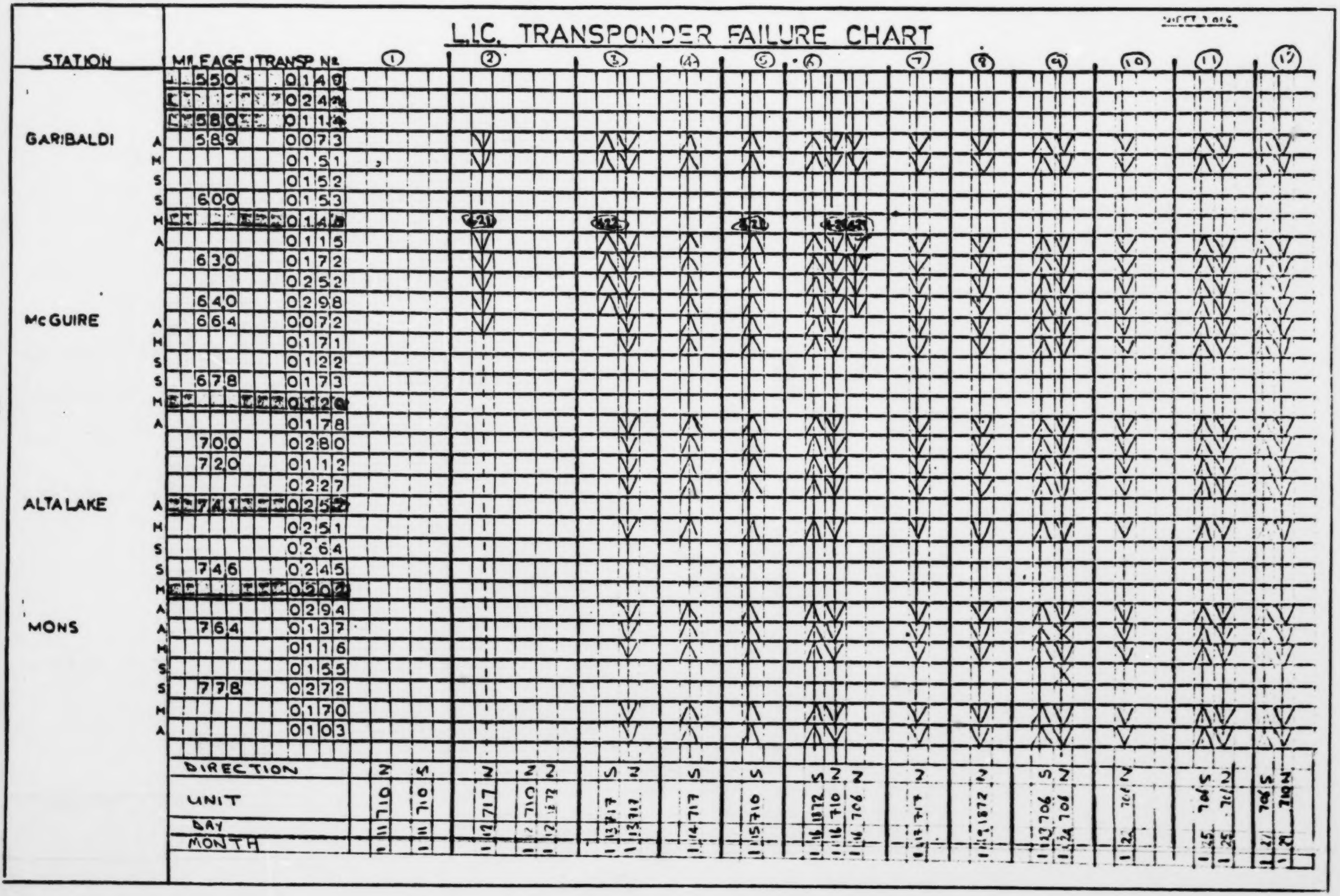
L.I.C. TRANSPONDER FAILURE CHART



L.I.C. TRANSPONDER FAILURE CHART



L.I.C. TRANSPONDER FAILURE CHART



SHEET 4 of 6

L.I.C. TRANSPONDER FAILURE CHART

STATION		MILEAGE	TRANSP No.	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫
		82.0	0248	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
			0268	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
		85.0	0170												
		86.0	0299	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
			0232	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
		88.0	0208												
TISDALL	A	89.6	0131	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	X ∨	∨
	M		0134	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	X ∨	∨
	S		0157												
	S	90.9	0129												
	M		0165	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	X ∨	∨
	A		0296	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	X ∨	∨
		93.0	0218	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
			0223	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
PEMBERTON	A	94.3	0108												
	M		0205												
	S		0286												
WYE SOUTH		94.4	0260												
			0226												
WYE NORTH		94.6	0217												
			0253												
PEMBERTON	S	95.0	0174												
	M		0102												
	A		0071	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
		97.0	0200	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
EVANS	A	98.7	0285	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
	M		0237	∧		∨	∧	∧	∧ ∨	∨	∨	∨	∨ ∧	∧ ∨	∨
	S		0258												
	S	98.9	0270												
	M		0292												
	A		0203												
(A.E.)		99.4	0212												
			021[illegible]												
DIRECTION				N S	N N N	S N	N	S	S N	N	N	N	N S	S N	[illegible] N
UNIT				710 710	717 710 1872	717 717	717	710	1872 710	717	1872	706	706 706	706 706	[illegible] 710
DAY				11 11	12 12 12	13 13	14	15	16 16	17	19	24	22 23	25 25	27 [illegible]
MONTH.				1 1	1 1 1	1 1	1	1	1 1	1	1	1	1 1	1 1	1 [illegible]

L.I.C. TRANSPONDER FAILURE CHART

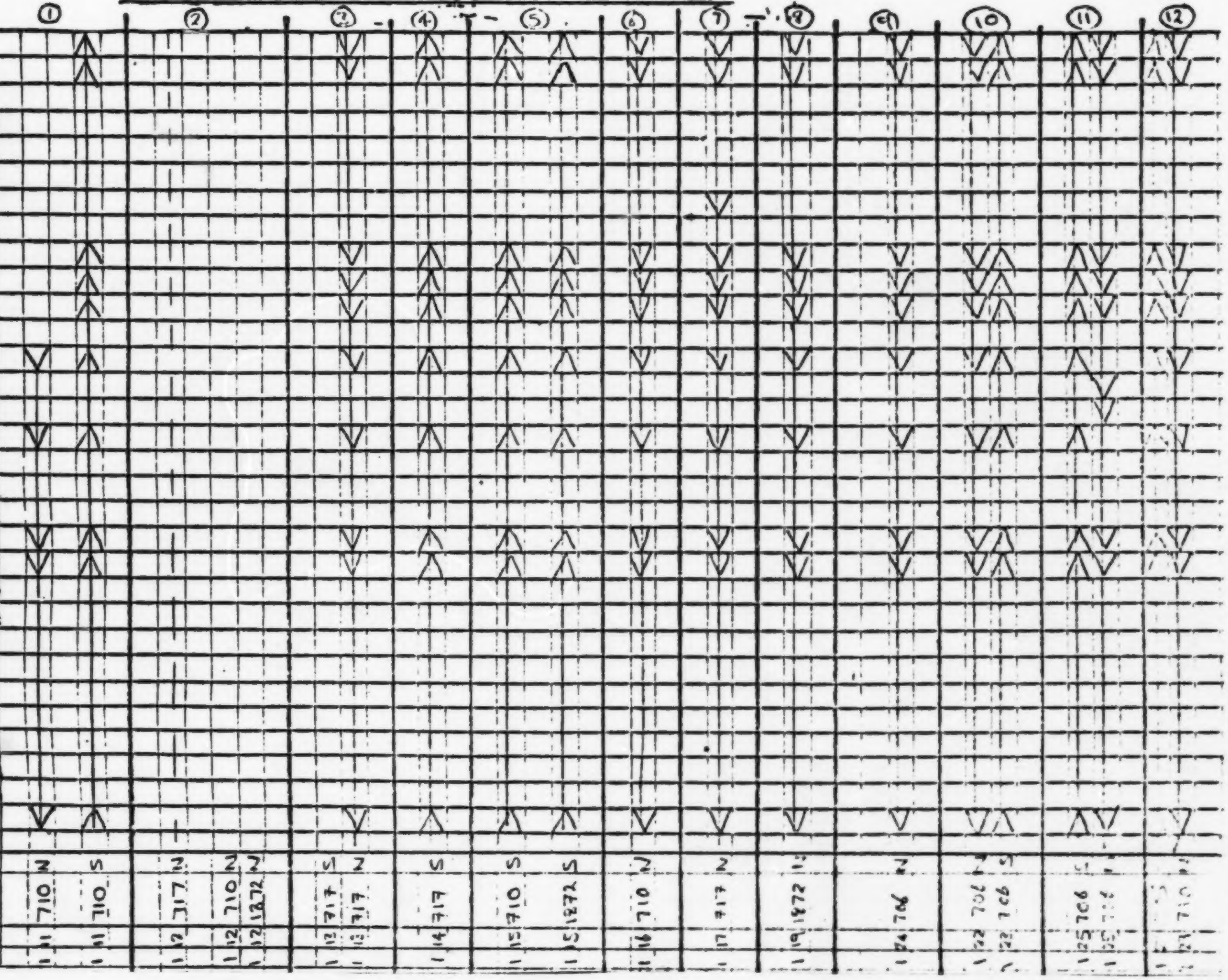
STATION		MILEAGE	TRANSP Nº
		1000	0069
		1030	0255
			0254
CREEKSIDE	A	1055	0150
	H		0159
	S		0133
	S	1066	0128
	H		0105
	A		0180
		1090	0263
			0211
BIRKEN	A	1119.5	0102
	H		0101
	S		0179
	S	1131	0127
	H		0177
	A		0160
(A.E.)		1137	0269
			0236
		1150	0273
		1180	0150
			0290
		1200	0209
DARCY	A	1223	0110
	H		0158
	S		0118
	S	1233	0139
	H		0181
	A		0120
		1250	0262
			0204

DIRECTION

UNIT

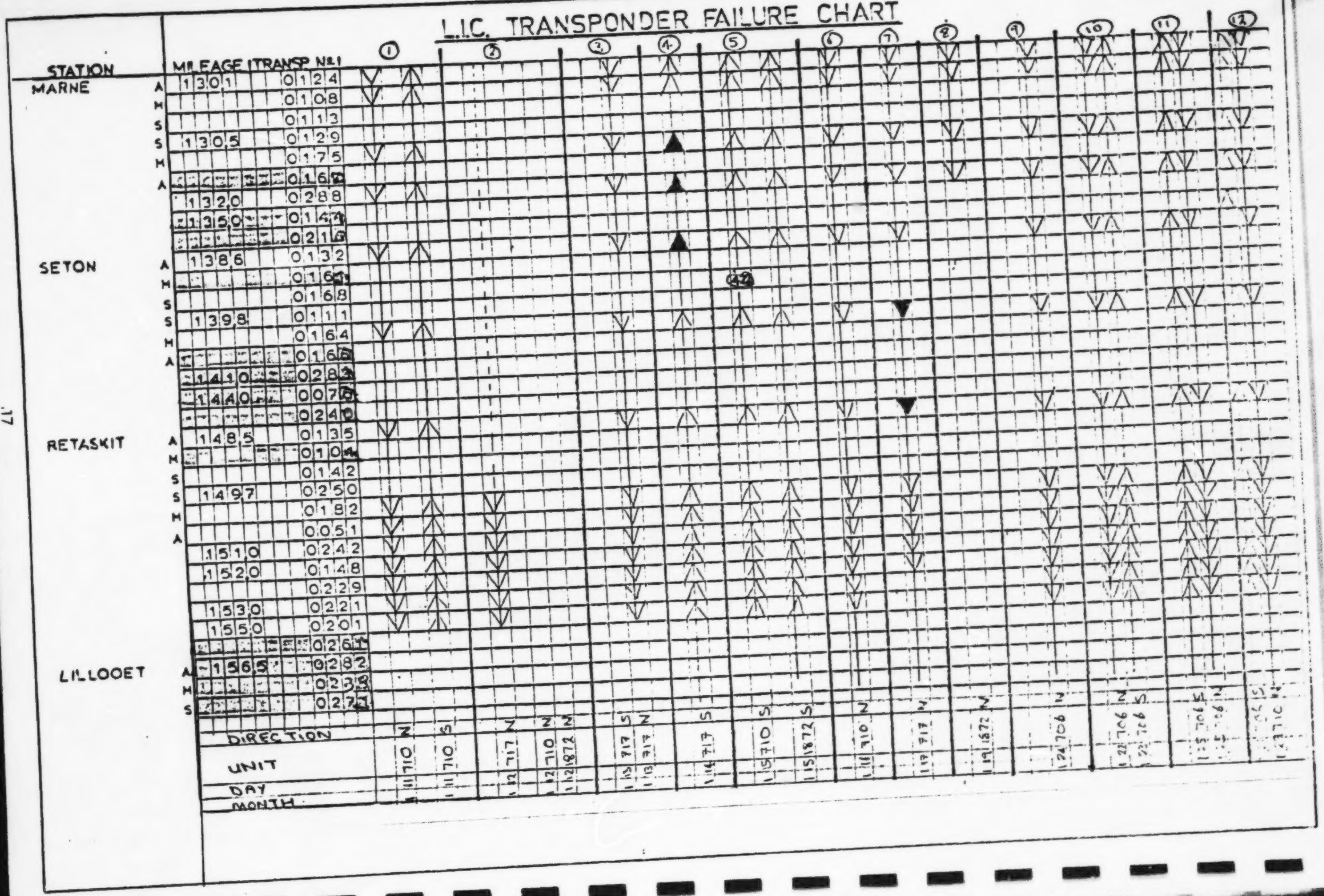
DAY

MONTH



SHEET 8 OF 8

L.I.C. TRANSPONDER FAILURE CHART



POOR

QUALITY

ORIGINAL